AFIT/GST/ENS/93M-08

ESTIMATING
TEST RANGE CAPACITY

THESIS

Paul A. McDaniel
Major, USAF

AFIT/GST/ENS/93M-08

AFIT/GST/ENS/93M-08

ESTIMATING
TEST RANGE CAPACITY

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

Paul A. McDaniel, B.S.
Major, USAF

March, 1993

THESIS APPROVAL

STUDENT: Major Paul A. McDaniel CLASS: GST-93M-08

THESIS TITLE: Estimating Test Range Capacity

DEFENSE DATE: 5 March 1993

COMMITTEE:	NAME/DEPARTMENT	SIGNATURE
Advisor	Major John J. Borsi/ENS	John J. Borsi
Reader	Major Wendell P. Simpson/LAS	Wendell P. Simpson

Acknowledgments

During the past six months of researching and writing my thesis, I had a great deal of help from many others to whom I'd like to express my appreciation.

First, I'd like to thank my sponsor, the 3246th TEST WING, for the excellent support provided in helping me gather pertinent data and background information for my study. I'd especially like to thank SSgt Scott Martin for his time and assistance in helping me sort through and understand the complicated nature of the range scheduling system.

I am deeply indebted to my thesis advisor, Major John Borsi, for his endless patience, guidance, and invaluable assistance. Without his insight and persistence my thesis, most certainly, would not have been possible.

I also owe a debt of gratitude to Major Wendell Simpson for the time and effort he spent in making my thesis "come together". His knowledge, and intuitive questions were extremely beneficial in helping me accomplish this thesis effort.

Most of all, I'd like to thank my wife Kim and two boys, Matthew and Kyle for their loving patience, devotion, and understanding that ultimately helped see me through this most challenging, but rewarding experience.

Paul Anthony McDaniel

Table of Contents

List of Figures

List of Tables

Abstract

The main focus of this thesis effort was to develop a means to estimate the capacity of the test range complex at Eglin AFB, Florida. For the purposes of this study, test range capacity was defined as the maximum number of missions, of a given set, that could possibly be supported by range resources on any given day. In trying to determine this number, the complexities of the overall multi-resource constrained scheduling problem dictated a more practical approach be taken in modeling the allocation process of range resources to test missions. Therefore, a series of three single-resource, 0-1 integer programming models depicting the allocation of Test Wing aircraft, radars, and range area resources were developed to produce an upper bound estimate of the range capacity for a given set of missions. In actual testing, the Range Area Allocation Model produced some poor results and therefore, cannot be used in its present form. However, both the Aircraft and Radar Models appear to produce legitimate upper bounds on range capacity in all cases. Nevertheless, to insure the goodness of these two models further testing is recommended. In addition, a single model depicting the allocation of these two resources and possibly several others, should be developed in order to better estimate range capacity.

ESTIMATING TEST RANGE CAPACITY

1. Introduction

1.1 Background

A number of Department of Defense (DOD) test ranges are located on various military complexes throughout the United States. A wide variety of military systems are tested and evaluated within these specially designated tracts of land, water, and airspace. One of the largest facilities is operated by the Air Force Development Test Center (AFDTC), located at Eglin AFB, Florida. AFDTC manages test ranges that encompass over 86,000 square miles of water in the adjacent Gulf of Mexico and over 700 square miles of land in northwestern Florida (4:1-1). A multitude of non-nuclear munitions, electronic combat, and navigation and guidance systems are tested and evaluated each day within this expansive test range complex.

The organization at Eglin AFB responsible for managing the overall test and evaluation program for AFDTC is the 3246th Test Wing (TW). In performing this task, the TW is outfitted with a variety of aircraft and highly instrumented ground facilities that must be coordinated for use to perform major tests on or above Eglin's ranges. One of the TW's primary functions, therefore, is to efficiently manage and schedule these assets, along with Eglin's test ranges, to support a variety of requested tests. Each test, referred to as a mission, may require the use of several ranges and facilities, along with other resources such as instrumented aircraft, drones, high-powered radars, cameras, telemetry frequencies and airborne electronic countermeasure equipment. Also, one of a number of mission profiles or scenarios providing the necessary flight and altitude tracks needed to conduct a particular test, is normally requested in addition to the above resources. As many as 100 missions are requested on any given day. Hence, with nearly 500 mission profiles, a vast array of test ranges and facilities, and the availability of over 1000 resources, the TW's scheduling and coordinating task is enormous and quite complex (4:1-2).

1.2 The Scheduling Process

The Range Scheduling Division (DOS) of the 3246th TW, has the primary responsibility for scheduling all missions conducted within the test range complex (2:1). One of their main objectives is to accommodate as many test missions as possible on any given day. With the aid of a computerized scheduling tool, the Resource Scheduling and Operational Management System (RESOMS), they first sort through and prioritize the various test mission requests before manually developing a single day's schedule (21). In this manner they're usually able to schedule the bulk of the daily test missions requested.

1.3 Six-Day Scheduling Cycle

Each day's schedule is preceded by a six-day process in which mission requests are first submitted by test engineers, sorted by type and mission priority, reviewed by several committees, and then wrung through a complex resource allocation process in which alternate resources and mission times are considered when scheduling conflicts exist between missions. If such conflicts are unresolvable, missions with higher priority take precedence. This process continues until all missions requested for a particular day have been reviewed, and are either scheduled or placed in a non-scheduled stand-by status in case a higher priority mission is canceled (21).

During this six-day cycle, Backup and Alternate Test Missions may also be requested. A Backup Mission is identical to a previously scheduled primary mission that is requested "to ensure that a mission is already in the scheduling cycle to replace the Primary Mission if it is canceled" (1:22). Backup Missions are usually requested one or two days after the primary is to be conducted (21). An Alternate Mission, on the other hand, is a mission that uses the same range resources as a Primary Mission scheduled on the same day. In the event the Primary Mission cancels, the Alternate Mission is ready to use the Primary Mission's allotted resources for its own test purposes (1:22). Alternate Missions differ significantly from Backup Missions in that they depend on the scheduling and subsequent cancellation of an associated Primary Mission in order to be accomplished (1:22).

Range schedulers spend a considerable amount of time and effort in accommodating as many mission requests as possible for given day. However, frequently they are unable to schedule every mission requested. As a consequence, a significant amount of time is also spent in trying to answer questions as to "why" a mission has not be scheduled. In both the scheduling process and in better explaining non-scheduled missions, a comparison of the actual schedule against range capacity would certainly be beneficial. To this point however, the TW has been unable to determine what the range capacity is, hence, it's been unavailable as a measure of comparison (16).

1.4 Range Capacity

Eglin's test range capacity cannot generically be defined as the maximum number of test missions that Eglin's range complex is capable of supporting over any given time frame. Due to a wide variety of tests and resource requirements requested on any given day such a definition would be meaningless at best. In fact, Eglin's range capacity is actually an elusive wide-ranging variable that is highly dependent upon the daily mix of requested test missions and the associated resources required. Therefore, for purposes of this study Eglin's test range capacity is defined as follows:

> " the ability of the test range complex to support or accommodate a select quantity of diverse test missions over a given span of time."

This equates to the maximum number in a given set of various type test missions, that can be supported by the ranges in an 8 to 12 hour workday. Once calculated, the daily range capacity can then be used not only to better justify non-scheduled missions, but also act as a benchmark for range schedulers to target. As such, it can be used to identify whether or not additional test missions can be accommodated within the present schedule. It could also be used to evaluate what effect mission priorities have on the number of scheduled missions, as well as, provide "forecasts" of expected workloads throughout the week. Ultimately, a method developed to estimate range capacity could be useful in providing insight into how resource availability affects the number and types of testing that can be supported at Eglin. This insight can then be used to better direct future investment capital aimed at expanding Eglin's testing capacity.

1.5 Problem Statement

3246 TW Schedulers would like to use the test capacity of Eglin's range complex to assess various scheduling issues. However, Eglin's test capacity is unknown and changes daily depending upon the types of missions and resources requested. Consequently, this thesis effort was centered on developing a means to estimate the variable capacity of Eglin's test range complex. In short:

"Given a set of requested open-air test missions to be scheduled on a particular day, estimate the maximum number of those missions (range capacity) that could be supported."

1.6 Overview of Subsequent Chapters

The first step taken in this thesis effort involved gaining a basic understanding of the specifics of the overall problem. This was accomplished through personal interviews and through direct observation of the daily scheduling process in action. Additional understanding was gained reading TW scheduling regulations, manuals, procedures, and operational directives. Following that, and throughout the remainder of this study, related topic areas were researched to gain an understanding of general scheduling concepts and solution methods that could be used in estimating range capacity. The information gleaned in this endeavor is contained in Chapter 2.

Chapter 3 provides a brief description of the overall resource model formulation used to help estimate Eglin's test range capacity. A discussion of the general strategy or approach taken in this study, along with a description of the general model formulation, its assumptions and operating constraints, as well as, common variables and parameters used in formulating a series of smaller resource models are presented in this chapter.

Chapters 4, 5 and 6 build upon the general information provided in Chapter 3. Specific resource model formulations for allocating TW aircraft, radars, and range areas to requesting test missions are separately contained in each of these chapters. A small example problem, illustrating the use of each resource model, is solved and analyzed following the model's description in each chapter.

Chapter 7 presents the results for each of the above models after actual TW data was used to test their performance. A summary of results along with an analysis of each resource model's effectiveness are discussed within this chapter.

Finally, Chapter 8 concludes with a brief summary of the major results of this study along with recommendations for additional research.

2. Literature Review

The main focus of this chapter is to present literature relevant to the scheduling of limited resources so that insights and possible methods of estimating range capacity can be developed. Topics on scheduling and complexity theory are therefore presented, along with ideas on general mathematical formulations and solution approaches for resource constrained problems.

2.1 Scheduling Theory

In general, a scheduling process involves the servicing of a fixed system of jobs (test missions) by a set of resources (aircraft, radars, range areas, etc.) over a given time period (one day), or as Rogers and White succinctly put it, "the allocation of shared resources, over time, to competing activities" (26:693). In this process, the tasks and resources may have specified properties or constraints that affect system behavior. Usually the main goal in scheduling is to arrange or sequence the system's tasks "to optimize or tend to optimize some desired performance measure" (10:2). In the case of Eglin's test range complex, the goal of a scheduling algorithm would be to maximize the number of test missions scheduled on any given day. The number scheduled would then equate to Eglin's test range "capacity" for that day's set of mission requests.

In general, the above scheduling approach would provide the means to estimate test range capacity, and thus, fulfill the primary objective of this thesis effort. However, no practical algorithms or procedures are known to exist for developing a schedule for this type of resource-constrained scheduling problem (4:2-6). Therefore, an alternate approach to estimating range capacity is necessary.

2.1.1 Constraints. Constraints are "simply anything that prevents the system from achieving a higher performance versus its goal" (14:43) In scheduling, there are basically three types of constraints or restrictions that limit the degree to which a goal or objective can be pursued. They are classified as technology, precedence, and resource constraints (15:5,48,197).

Technology constraints are those that demand that each operation within an activity be processed in some particular order (15:5). For example, painting the walls in a new home (activity) may require several undercoats of primer (operation A) before the first coat of paint (operation B). Examining this level of detail for each test mission is unnecessary in this study. Therefore, technology constraints do not apply.

On the other hand, precedence constraints can play a significant role in this study. They are constraints that demand that certain activities (versus operations within an activity) be processed before another (15:48). Hence, these constraints would specify that certain test missions be given priority status ahead of others in the scheduling process. Thus, they could incorporate the present test mission priority system established by the TW.

Resource constraints are a major factor in scheduling and usually are the most limiting of the three. They are constraints that address the availability of each resource used in the process (15:197). Thus, in allocating range resources, a resource constraint can be used to restrict the availability of certain specific resources, as well as, non-specific, general classes of resources. For example, many times a test mission may request to work with one particular F-15 aircraft that's specially instrumented, along with an additional F-15 to act as a chase ship. In this instance, a specific resource constraint would allow the modified F-15 to be allocated only if it hasn't been allocated to another mission. A general resource constraint would then allow the additional F-15 to be allocated as long as there's an F-15 available in the general pool of F-15 resources.

2.1.2 Performance Measures. Once all constraints addressed in a problem are satisfied and a problem is considered feasible, an objective or measure of performance can be sought. However, there may exist "numerous, complex, and often conflicting" goals that one may wish to pursue (15:9). For some, trying to minimize the time when the last job in a schedule is completed may be the main objective. For others, minimizing the number of jobs completed after a certain time period (tardy jobs) may be more important. And yet for another, minimizing or maximizing the number of unfinished or finished jobs during a specific time period is more relevant. Determining what measure of performance is best in a particular situation is oftentimes difficult since usually more than one option is available. In estimating range capacity, a logical objective would be to maximize the number of scheduled missions over a given time frame.

2.2 Complexity Theory

Problems come in different degrees of difficulty from those that are "provably unsolvable" to those that are defined as "well solved" (19:102). Usually, the computational time or number of elementary computer operations needed by an algorithm to solve a specified problem instance, determines at what level that problem exists. Therefore, for the most difficult problems that are "provably unsolvable", no solution algorithms exist while numerous and efficient solution algorithms exist for the "well-solved" class of problems. In between these two extremes lies a large group of problems classified as "NP-Complete" which currently cannot be solved efficiently. The computational time required to solve these problems, via known digital computer algorithms, increases exponentially as the size of these problems increase (15:148). Well-known examples of NP-complete problems include the traveling salesmen and the general m-processor, n-job scheduling problems, both of which typically require a heuristic to determine an approximation to the optimal solution (10:124). Heuristic methods normally provide the most practical approach to such problems. They often consist of simple scheduling rules that do not guarantee optimality, but are capable of producing reasonably good suboptimal schedules (4:2-6). To preclude wasting time and effort, it's important to determine early on whether or not a problem is NP-complete so that a more pragmatic solution approach, such as a heuristic, can be pursued if necessary (3:139).

2.3 Resource Constrained Scheduling (RCS) Problems

Resource Constrained Scheduling (RCS) refers to problems that deal with scheduling activities under limited time and resource constraints (27:412). These types of problems are surrounded by enormous computational complexities which has earned them the classification of NP-complete (24:30). Common to such problems are activities of known duration that need to be scheduled within a certain time frame, along with predetermined levels of resources that are limited in quantity (27:412). The daily scheduling of test missions and their requested resources would fall within this description, and therefore, can be considered a Resource Constrained Scheduling problem.

2.4 Solution Approaches to RCS Problems

Optimization models of RCS problems are typically cast in terms of integer programming (18:50). Integer programming (IP), simply defined, is a "linear program in which some or all of the variables are required to be non-negative integers" (28:457) As such, IP's are used to model situations in which fractional solutions are unacceptable. For instance, in scheduling test missions, it would be inappropriate to schedule only half an aircraft to any given test mission. An integer variable specification would ensure that either all or none of the resources required by a particular mission are allocated to that mission. This example also highlights the special case of zero/one IP where binary decisions such as "yes" or "no", "go" or "no go", "schedule" or "do not schedule" can be modeled using zero or one to represent each decision. Thus, in real-life, many situations can be formulated as an IP. But even so, it should be noted that IP problems are not always easy to solve. For although "the integer program is very general and useful model, the analyst should be aware that solution techniques are very limited," for IP problems include some of the hardest problems found in Math Programming (17:2). In fact, "no non-exponential algorithms have been discovered for general integer or mixed integer programs", thus, depending on their size, IP problems can be extremely difficult to solve (17:2). Whereas the practical range of variables for an LP may run in the tens of thousands, for an IP problem, the practical range is usually in the hundred's (17:2). Hence, rather than solve the IP problem, many times a less constrained, more *relaxed*, version of the problem is solved instead, in order to approximate the true solution. Such an LP relaxation strips away the zero/one or integer variable constraints of the IP thus, effectively transforming the problem into a simpler, much easier to solve LP formulation. Since every feasible solution for the IP is feasible for its corresponding LP relaxation, a *bound* on the optimal IP solution can be specified. Therefore, if the solution of the LP relaxation is also integral, then the solution is also optimal for the IP problem (28:458).

Exhaustive Enumeration is one possible method of solving an IP problem. It involves generating all possible solutions to a problem before determining which is best. This approach however, is not practical for problems of moderate size for the number of possible solutions increases exponentially with the number of variables found in the problem (17:10). For example, in determining a schedule for 13 test missions, there would be 13! or over 6,000,000,000 possible sequences. Thus, in many instances, the task of enumerating and evaluating all possible solutions would be enormous even for the most powerful computer. Instead, a more practical approach would be to use bounding rules with the above enumeration process to help eliminate a number of inferior solutions where possible. Implicit enumeration or branch and bound methods, "fathom" or cut off all solutions known to be subordinate to a another. Thus, many times a large number of possible solutions can be discarded without having been explicitly evaluated. Hence, it's possible to solve many IP problems of significant size using implicit enumeration methods. However, it should be noted, that such methods may still require enumerating a significant portion of all possible solutions, and thus, cannot guarantee to generate a solution within a reasonable amount of time.

Common to all optimization approaches to the IP problem is the fact that computational time is highly sensitive to the size of the problem at hand. The computational time required can increase explosively as the number of variables and constraints increase. Therefore, in many problem instances, heuristic solution methods are often implemented, especially in the case of moderate sized RCS problems (13:18). In fact, in past studies, the scheduling of multiple resources has generally been approached using heuristics, although some optimizing techniques have also been attempted. The results, howeve indicate "only heuristic-based procedures are realistic for practical problems" and that "heuristic procedures are necessary for assigning priorities to activities when resource conflicts arise" (11:396). Even though heuristic solution approaches do not guarantee optimality, they are usually the methods of choice for RCS problems.

As discussed earlier, the daily scheduling of test missions and their requested resources at Eglin can be considered a RCS problem. As such, optimal daily schedules are extremely difficult to attain while heuristic solution procedures are necessary to approximate the best schedules possible. In the same light, determining the "exact" daily range capacity would be just as difficult if not impractical. Thus, based on the size of the problem, determining useful bounds on range capacity using a heuristic approached is appropriate.

3. General Resource Allocation Formulation

This chapter outlines the general resource allocation formulation used to help estimate Eglin's daily test range capacity. Although the formulation itself was too difficult to implement and solve within a single model, it was possible to split the formulation into a series of smaller resource specific variations that could be modeled as separate zero/one integer (IP) programs. These variations are presented over the next three chapters along with small example problems used to highlight each formulation's main features. By breaking down the general formulation, however, only an estimate on an upper limit to range capacity could be achieved.

3.1 General Overall Approach

As presented in Chapter 2, the overall problem of scheduling test missions with a limited number of available resources is what's often referred to as a resource constrained scheduling (RCS) problem. Estimating Eglin's test range capacity can be viewed as a special case of this larger, more complicated problem.

As eluded to above, if all test range resources could collectively be modeled in one large allocation process, then a true estimate of test range capacity could be resolved and specified for a given set of missions. However, since such a model is too large to be practical, a series of smaller models depicting the allocation of some of the more "critical" TW resources were used instead to produce an upper bound estimate of range capacity for a given set of missions. Critical resources are defined as those that tend to limit the number of missions scheduled, and thus, would most likely affect test range capacity. The non-availability of such TW resources as aircraft, radars, and range areas were frequently listed as reasons for non-scheduled missions in the past. Hence, they were chosen to be included in the initial set of critical resources to be modeled in this study.

3.2 Estimating an Upper Bound

Due to computational complexity considerations, a series of single-resource allocation models were formulated to estimate range capacity. Each model determines the maximum number of missions from a given set that can be supported by a "single" critical resource. If modeled correctly, the outcome of each model would always equal or exceed the true range capacity for that given set of missions. Since these model estimates of range capacity are upper bounds, the minimum value of a series of bounds is also an upper bound.

One of the main limitations of using a series of single-resource allocation models however, is that significant interactions between range resources are not accounted for. For example, some test missions may require certain radars be allocated in conjunction with particular overwater range areas in order to provide the best radar coverage available. Hence, both types of resources need to be considered simultaneously during the allocation process. Additional research is therefore warranted to account for interaction between range resources.

3.3 Description of General Resource Allocation Formulation

In each of the three resource allocation formulations that follow this chapter, the main objective is to maximize the number of test missions that can be allocated all the modeled TW resources they're requesting. In the process, each mission can request specific, as well as, general resources for its test. For example, a mission may need a specially instrumented F15 tail #977 for its test along with an additional F15 to act as a chase ship. In this instance, a specific request is made out for F15, #111 while a general request is made out for "any" F15 aircraft. Therefore, modeled resources are listed in both specific and general categories. From these listings each modeled resource can then be "specified" in a request by either its resource number s or if a specific resource is not necessary, from a "general" pool of like-kind resources g. The tables found in

Appendix A collectively display the three modeled TW resources in 66 general resource categories broken down into 152 individual subcategories.

To model the use of each resource, the 12 hour testing day is broken up into T distinct, non-overlapping time periods in which a single resource can support, at most, one test mission. Actual operational usage of each modeled resource dictates the number of periods T. In the aircraft formulation for example, T was set to two because operational restrictions normally allow an aircraft to support, at most, two missions a day. Also, since the models do not account for maintenance or other down times, all resources are assumed available in each period. Thus, on any given day, each resource can support up to T of J total test missions.

In each model, each resource s can be assigned to, at most, one test mission j in a given time period t. Also, within this time period t, the total number of requested resources from each general category g (which includes both specific and general resource requests) cannot exceed the total number available. For instance, if two specific aircraft along with three "unspecified" aircraft are requested from the same general category, unless a total of five aircraft are available within that category, some missions may not be supported.

3.3.1 Additional Assumptions and Modeling Considerations. Other inherent underlying assumptions and operating constraints, not included in the above discussion, are summarized as follows:

First, to narrow the scope of this study, only open-air missions will be examined. This includes all missions categories that employ aircraft resources.

Second, to initially simplify the formulation and solution of each mathematical model, test mission priority will be ignored.

Third, although each test mission usually requests a specific time of day in which to operate, this facet of the request will be ignored since the actual sequence or scheduling of each test will not be accomplished in this study. Note that constraining a scheduling process by considering mission priority or time of day requests can only decrease the number of missions supported in a day. Therefore, an upper bound on range capacity is still achieved when ignoring these factors.

Fourth, in accordance with the TW's aircraft maintenance restriction, the testing day is considered to be 12 hours long - beginning from the start of the first test mission to end of the last (21). Lesser pilot duty day limitations of 8 to 10 hours (placed on test missions utilizing the same pilot) are not a factor if it's assumed that such related missions always operate within 8 to 10 hours of each other in an ideal schedule.

Finally, since Special Operations and night flying missions are few in number and easily supportable outside the 12 hour testing day window, they are not considered in the allocation process. For accounting purposes, when these missions appear in the requesting data sets, all their requested resources are assumed to have been allocated within the first time period.

3.3.2 Common Resource Model Variables and Parameters.

The following are common variables and parameters found within each resource model formulation:

Given:

g = "General" resource category - refers to a group of commonly related resources.

s = "Specified" resource number - refers to a particular resource within a general category g.

j = Requesting test mission; j = 1,...,J.

t = Testing period; t = 1,...,T.

Parameters:

S = Set of "specified" or specifically identified resources requested by test mission j.

G = Set of "general" or non-specifically identified resources requested by test mission j.

TAV_g = Total number of resource type g available for allocation.

$$REQ_{sj} = \begin{cases} 1 & \text{if resource s is required by test mission j} \\ 0 & \text{otherwise} \end{cases}$$

$$REQ_{gj} = \begin{cases} 1 & \text{if resource g is required by test mission j} \\ 0 & \text{otherwise} \end{cases}$$

Variables:

$$x_{tj} = \begin{cases} 1 & \text{if in period t, test mission j can be allocated} \\ & \text{all its requested "g" and "s" resources} \\ 0 & \text{otherwise} \end{cases}$$

3.4 General Resource Model Formulation

Given the above variables and parameters, along with the general constraints and assumptions presented in this chapter, the General Resource Allocation Formulation is as follows:

Objective Function:

$$MAX \sum_{t \in T} \sum_{j \in J} x_{tj}$$

Subject To:

$$\sum_{j \in J} (REQ_{sj} \cdot x_{tj}) \leq 1, \qquad \forall\, s \in S \quad \forall\, t \in T \qquad \text{"Specific Constraint"}$$

$$\sum_{j \in J} (REQ_{gj} \cdot x_{tj}) \leq TAV_{gt} \qquad \forall\, g \in G \quad \forall\, t \in T \qquad \text{"General Constraint"}$$

$$\sum_{t \in T} x_{tj} \leq 1, \qquad \forall\, j \in J \qquad \text{"Time Period Constraint"}$$

$$x_{tj} = \{0,1\} \qquad t = 1,\ldots,T \qquad j = 1,\ldots,J$$

In the next three chapters, the above general model formulation was specifically tailored to portray the allocation process for each of the three TW resource chosen in this study. Hence, aircraft, radars, and range area resources are explicitly examined to see how each limits the scheduling of a set of open-air test missions. Hence, for a given set of mission requests, the most constraining resource of the three would then provide an upper bound estimate of the maximum number of missions that could possibly be scheduled on Eglin's test ranges in a day.

4. Aircraft Model Formulation

4.1 Allocating Aircraft Resources

The objective of the following mathematical model is to determine the maximum number of missions, of a given set, that can be allocated their requested **aircraft** resources without violating any general or aircraft specific constraints or assumptions.

4.1.1 Aircraft Specific Modeling Assumptions. When allocating aircraft to requesting test missions, several aircraft specific modeling assumptions or considerations were made in formulating the aircraft allocation model.

First, although test engineers sometimes list alternate aircraft that can be used in their testing, this study only considers the primary aircraft requested for their test. This greatly simplifies the allocation process while only marginally effecting the usefulness of the final results since requests for backup aircraft are relatively few in number (21).

Second, each testing day is broken up into two non-overlapping time periods in which each aircraft resource (except tankers) can support at most, one test mission in each period. Hence, a single aircraft can support no more than two test missions in a day. Although TW aircraft are capable and on occasion support more than two missions in a day, such instances are rare and undesirable. Additional missions are detrimental to the aircraft's life cycle, as well as, demanding on maintenance and manpower requirements (21). The time and length of each period is inconsequential since they can be adjusted to conform to most any schedule. Therefore, the model ignores the specif cs of scheduling (i.e., mission duration, takeoff times, turnaround times, etc.) and concentrates on the broader issue of the "capacity" of each aircraft.

Third, it's assumed that one tanker aircraft resource, either a KC-135 or KC-10, is available every day. Although the TW does not own any tanker resources, such resources are made available from other operational flying wings and have been contracted for months in advance. Depending on tanker type, between two to four test missions can be supported per period each of which can involve more than one aircraft (21). If tanker type is unknown, a KC-10 is assumed to be available since it supports the larger number of missions, and thus, provides a higher bound on the number of allocated missions.

And finally, all aircraft assigned to the TW are assumed to be maintenance free and always available upon request. Although this is hardly the case, unscheduled maintenance downtime is highly unpredictable and can only be depicted in a general sense. Additional research might look at making a portion of the total number of aircraft in each general category unavailable for allocation to examine whether or not maintenance downtime could be modeled in this manner. This study, however, assumes every TW aircraft is available and deemed able to fly twice a day.

4.1.2 Aircraft Allocation Formulation.

Objective Function:

$$MAX \quad \sum_{t \in T} \sum_{j \in J} x_{tj} \tag{4.1}$$

Subject To:

$$\sum_{j \in J} (REQ_{sj} \cdot x_{tj}) \leq 1, \qquad \forall\, s \in S, \quad t = 1,2 \tag{4.2}$$

$$\sum_{j \in J} (REQ_{gj} \cdot x_{tj}) \leq TAV_g, \qquad \forall\, g \in G, \quad t = 1,2 \tag{4.3}$$

$$x_{1j} + x_{2j} \leq 1, \qquad \forall\, j \in J \tag{4.4}$$

$$x_{tj} \in \{0,1\} \qquad t = 1,2 \qquad j = 1,\ldots,J$$

Constraints 4.2 and 4.3 ensure that the allocated number of "general" and "specified" aircraft resources do not exceed the total number available in each time period.

Constraint 4.4 limits each test mission to one of two periods during the day or to neither period when all aircraft allocations cannot be made. Thus, it allows a given aircraft to support up to two different missions in a day since all aircraft can be allocated once in each time period. In addition, constraint 4.4 prevents partial allocation of aircraft resources to test missions when any or all aircraft requested by a mission cannot be allocated. In such an instance, a test mission will not be assigned a time period, and thus, would be listed as non-scheduled.

4.2 Allocating Aircraft Resources (Example Problem)

The following example problem illustrates the use of the aircraft allocation model in determining the maximum number of missions, in a given set, that can be allocated all their requested aircraft resources in a two-period day. No other Test Wing resources are considered in the process.

On the next page, Table 4.1 lists the available TW aircraft resources considered in this example problem. Note that the table is similar to the actual aircraft resource tables found in Appendix A and that it's split into general "G" and specified "S" sets of aircraft categories with each individual aircraft "s" belonging to a general group "g". Also note that the first five categories are the same for "g" and "s". The single aircraft identified in these categories are uniquely modified for a specific test purpose and cannot be grouped with any other. For the most part, these aircraft cannot be used for anything other than what they've been specifically "designated" (21).

TABLE 4.1

SAMPLE SET OF TEST WING AIRCRAFT RESOURCES
(For Example Aircraft Allocation Problem)

g	TAV_g	s	Type	Description
1	1	1	F15	Set of specially modified or instrumented Test Wing aircraft. These aircraft will not fly any mission other than what they've been designated/ modified to fly.
2	1	2	F16	
3	1	3	F16	
4	1	4	F16	
5	1	5	F16	
6	6	6-11	F15	Set of unmodified or semi-modified Test Wing aircraft. These aircraft can be configured to fly all missions except those designated for aircraft in the above set.
7	6	12-17	F16	
8	2	18-19	F111	
9	2	20-21	RF4	
10	2	22-23	UH1N	

Table 4.2 below, categorizes each type of tanker aircraft and identifies their capabilities. A similar table can be found in Appendix A.

TABLE 4.2

TANKER AIRCRAFT SUPPORT
(For Example Aircraft Allocation Problem)

g	TAV_g	s	Type	Description
11	4	24	KC10	Each KC10 can support 4 missions
12	2	25	KC135	Each KC135 can support 2 missions

On the next page, Figure 4.1 depicts both "general" and "specified" aircraft resource requirements for a given set of 17 test missions requested for a particular day. Test mission 1 (TM1) for example, specifically requests F15 #10 from general category 6 and F16 #12 from general category 7. In addition, it also requests a second "non-specific" F15 from general category 6. Thus, TM1 is requesting the use of two "specified" and one "general" type aircraft.

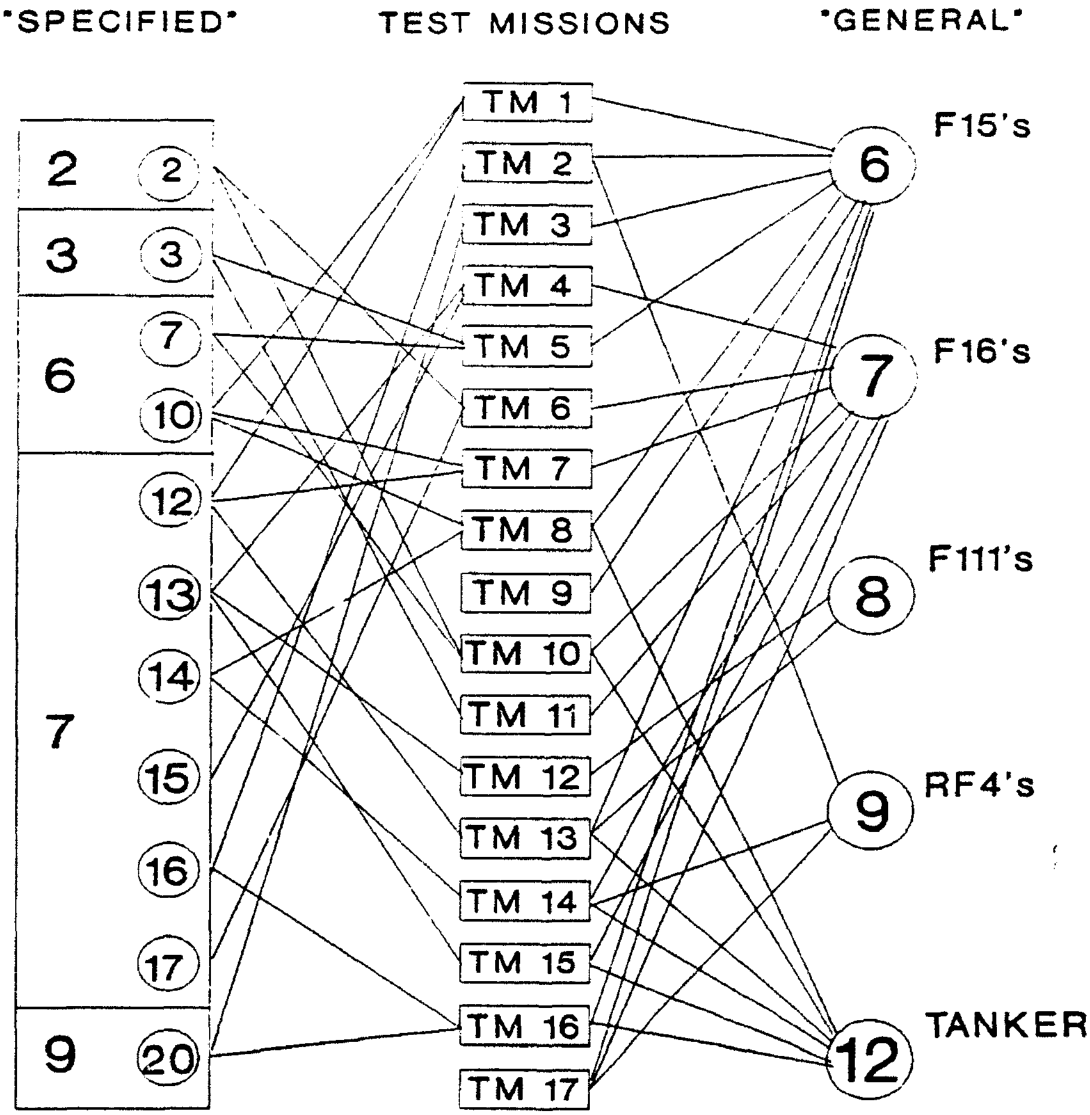

Figure 4.1 "General" and "Specified" Aircraft Resource Requirements (Aircraft Allocation Example).

In Figure 4.1, test mission requirements exceed the number of available aircraft resources which is typically the case found in normal day to day scheduling operations at Eglin.

In this example, the overall goal is to schedule as many of the 17 test missions as possible for a specific day. Hence, the main objective in the scheduling process is:

$$MAX\ Z = \sum_{t=1}^{2} \sum_{j=1}^{17} x_{tj} \qquad (4.1)$$

The "specified" aircraft resource requirements, depicted in Figure 4.1 for each test mission j, are shown in Table 4.3 on the next page. Total requirements for each specified category "s" or ΣREQ_{sj}'s are tallied across each row and found along the right-hand side of the table. A scheduling conflict, whereby a mission cannot be supported, is unavoidable when this sum is greater than two since each aircraft can only support at most, two missions a day.

Table 4.3

"SPECIFIED" AIRCRAFT REQUIREMENTS (REQ_{sj})
(For Example Aircraft Allocation Problem)

s \ Test Mission j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	$\Sigma\, REQ_{sj}$
2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2
3	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2
7	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	2
10	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	3
12	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3
13	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	3
14	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
20	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
$\lvert S_j \rvert$	2	1	1	2	2	2	2	2	0	2	1	1	1	1	1	2	0	

Thus, at least three conflicts will exist when attempting to allocate the above "specified" aircraft resources to the 17 test missions in the given set.

The following "specified" constraints from the Aircraft Allocation Formulation ensure that if a test is scheduled within a period t, then its requested aircraft are not assigned to any other missions within that same period:

$$\sum_{j=1}^{17} (REQ_{sj} \cdot x_{tj}) \leq 1, \qquad \forall\, s \in S, \quad t = 1,2 \tag{4.2}$$

$$x_{1,j} \in \{0,1\}, \quad x_{2,j} \in \{0,1\}, \quad j = 1,\ldots,17$$

In similar fashion, the "general" aircraft resource requirements as depicted in Figure 4.1 for each test mission j, are shown in Table 4.4 below. Note that tanker resource types 11 and 12 are also included in the table.

TABLE 4.4

"GENERAL" AIRCRAFT REQUIREMENTS (REQ_{gj})
(For Aircraft Allocation Example Problem)

Test Mission j

g	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	ΣREQ_{gj}
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2
3	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	2	1	1	0	2	0	1	2	1	1	0	0	1	0	0	1	1	14
7	1	1	0	3	0	2	2	1	0	1	1	1	1	2	2	1	1	20
8	0	0	0	0	1	0	0	0	1	0	1	1	1	0	0	0	0	5
9	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	5
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	0	6
$\lvert G_j \rvert$	3	2	2	3	3	3	3	4	1	4	2	2	4	4	3	4	2	

In Table 4.4, specified aircraft requirements are included within each test mission's general aircraft requirement count. Hence, since categories 1 through 5 contain only a single aircraft, these categories are identical to those listed in Table 4.3 for specified aircraft requirements. Therefore, the constraints associated with these five categories are redundant and can be ignored General categories 6 through 12, however, need to adhere to the following "general" constraints from the Aircraft

Allocation Formulation:

$$\sum_{j=1}^{17} (REQ_{gj} \cdot x_{tj}) \leq TAV_g, \qquad \begin{array}{l} \forall\, g \in G \\ t = 1,2 \end{array} \tag{4.3}$$

$$x_{1,j} \in \{0,1\}, \quad x_{2,j} \in \{0,1\}, \quad j = 1,\ldots,17$$

Finally, to ensure that a test mission is not scheduled for more than one time period, the last set of constraints found in the Aircraft Allocation Formulation must be satisfied:

$$x_{1j} + x_{2j} \leq 1, \qquad j = 1,\ldots,17 \tag{4.4}$$

$$x_{1,j} \in \{0,1\}, \quad x_{2,j} \in \{0,1\}, \quad j = 1,\ldots,17$$

Using the LINDO (Linear Interactive and Discrete Optimizer) linear program solver, an optimal solution to this example aircraft allocation problem was generated (see Appendix B) and is summarized below:

$$\begin{array}{llll} Z_{max} = 13 & \text{with} & x_{1j} = 1 & \text{for } j = 5,\ 6,\ 8,\ 12,\ 16,\ 17 \\ & & x_{2j} = 1 & \text{for } j = 1,\ 2,\ 3,\ 9,\ 10,\ 11,\ 15 \\ & \text{and} & x_{tj} = 0 & \text{for } j = 4,\ 7,\ 13,\ 14 \end{array}$$

Therefore, missions 5, 6, 8, 12, 16, and 17 were allocated all their requested aircraft in period one while missions 1, 2, 3, 9, 10, 11, and 15 were allocated all their requested aircraft in period two. Missions 4, 7, 13, and 14 could not be supported in either period.

In this example, other optimal distributions of aircraft to test missions may be possible. However, in no case will the maximum number of allocated missions or Z_{max} exceed 13. Thus, Z_{max} provides us with an upper bound on the number of missions that can be scheduled, given the mix of requested missions presented in this example problem.

5. *Radar Model Formulation*

5.1 Allocating Radar Resources

The objective of the following mathematical model is to determine the maximum number of missions, of a given set, that can be allocated their requested **radar** resources without violating any general or radar specific constraints or assumptions.

5.1.1 Radar Specific Modeling Assumptions. When allocating radars to requesting test missions, several radar specific modeling assumptions or considerations were used in formulating the radar allocation model.

First, each testing day is broken up into five, non-overlapping time periods in which tracking radars can support at most one test mission per period while all others (due to manning limitations) can support only one test mission in each of four periods. These limitations are based upon the number of test missions that can feasibly be conducted within a standard military or contract radar operator's workday at Eglin. The standard workday for military operators manning the tracking radars, is between 8 to 10 hours long, while contract operators manning the remaining radars, are "contracted" for up to 8 hours a day after which they're paid overtime (21). To stay within these time constraints, the number of test missions, which vary in length between 1.5 and 3.0 hours must be limited. Of the type missions that last 3.0 hours (ie., Flutter and Amraam missions), normally not more than one, and never more than two can be handled within a given day (21). Hence, when assuming a normal day where only one 3.0 hour mission has been scheduled, each tracking radar can support up to four additional 1.5 hour missions, in conjunction with the one 3.0 hour mission in a 10 hour day, while all other radars can support an additional three 1.5 hour missions in an 8 hour contract worker's workday. Thus, tracking radars are given five time periods in which to work in, while all others are given four.

Contract manning and maintenance limitations also play a significant role in the number of specific radars that can operate each day at Eglin. These limitations are summarized below.

(a) Four of five A20 tracking radars per day.

(b) Two of four of the following radars per day:
- A13MPQ46
- A13NIKETRR
- A13NIKETTRV
- A12WESTIA

(c) Two of three of the following radars per day:
- B10WEST4B
- B10WEST5
- B1WEST3

(d) Three of five of the following radars per day:
- A30FLYCATCHER
- A30ROLAND
- A30SADS8R
- A30WEST11C
- A30XM40

(e) One of the following radars per day:
- A3MPS19-125
- A3MPS19-161

The radars listed in (a) and (e) are assumed to be homogeneous (identical) whereby, one radar can be substituted by another. Therefore, the limitations placed on these two groups of radars can be considered in general terms where only the number of radars allocated in each period is constrained. On the other hand, radars listed in (b), (c), and (d) are not homogeneous. Normally the same sets of radars in each of these groups must be used through the entire day. However, given a two hour time period in which to make a switch, a different set of radars from each group could be made available. Historically, such a switch has been necessary only four or five times a year. In these instances, if required, contractor overtime was authorized to avoid reducing the number of supported missions (20). Hence, the limitations placed on these three groups of radars can also be considered under the same general terms as those in (a) and (e).

One additional assumption was made in formulating the Radar Allocation Model. Similar to the Aircraft Formulation, the Radar Formulation assumes radar warm-up and turn-around times (on average between 15-30 minutes) can be ignored when the "capacity" of the radars is the main focus of attention. This assumes the necessary slack time is generally available within or around each separate non-overlapping time period.

5.1.2 Radar Specific Parameters. The following parameters are specific to radar and are in addition to the general variables and parameters listed in chapter 3:

STR = Set of "Specified" categories of tracking radars (See Appendix A, Table A.5).

GTR = Set of "General" categories of tracking radars. (See Appendix A, Table A.5).

5.1.3 Radar Allocation Formulation.

Objective Function:

$$MAX \sum_{t \in T} \sum_{j \in J} x_{tj} \tag{5.1}$$

Subject To:

$$\sum_{j \in J} (REQ_{sj} \cdot x_{1j}) \leq 1, \qquad \forall\, s \in STR \tag{5.2}$$

$$\sum_{j \in J} (REQ_{sj} \cdot x_{tj}) \leq 1, \qquad \forall\, s \in S,\ t = 2,3,4,5 \tag{5.3}$$

$$\sum_{j \in J} (REQ_{gj} \cdot x_{1j}) \leq TAV_g, \qquad \forall\, g \in GTR \tag{5.4}$$

$$\sum_{g \notin GTR} \sum_{j \in J} (REQ_{gj} \cdot x_{1j}) = 0 \tag{5.5}$$

$$\sum_{j \in J} (REQ_{gj} \cdot x_{tj}) \leq TAV_g, \qquad \forall\, g \in G,\ t = 2,3,4,5 \tag{5.6}$$

$$\sum_{t \in T} x_{tj} \leq 1, \qquad \forall\, j \in J \tag{5.7}$$

$x_{tj} \in \{0,1\} \qquad t = 1,\ldots,5 \qquad j = 1,\ldots,J$

The above constraints are similar to those found in the aircraft allocation formulation. Specific constraints 5.2 and 5.3, along with general constraints 5.4, 5.5, and 5.6 ensure that the allocated number of specified and general radar resources do not exceed the number available in each time period. Note however, that of these constraints, 5.2, 5.4, and 5.5 pertain specifically to tracking radars operating in period t = 1. These three constraints allow tracking radars an additional allocation period.

Constraint 5.7 ties the formulation together by limiting each test mission to one of five periods during the day. Thus, it allows tracking radars the capability to support up to five different missions in a day while all others can support up to four. As in the aircraft formulation, this constraint also prevents partial allocation of radar resources to test missions when any or all requested radars cannot be provided. In such an instance, a test mission would not be assigned a time period, and thus, would be listed as non-scheduled.

Operational manning and maintenance limitations are incorporated in the value of TAV_g or the total number of general radar resources that are available during any one time period. These values are listed in Table A.5 of Appendix A.

5.2 Allocating Radar Resources (Example Problem)

The following example problem illustrates the use of the radar allocation model in determining the maximum number of missions, of a given set, that can be allocated all their requested radar resources in a five-period day. No other TW resources are considered in the process.

Table 5.1 lists the available Test Wing radar resources considered in this example problem. Note that the table lists general "G" and specified "S" sets of radars and that each individual radar "s" belongs to a general group "g".

TABLE 5.1

SAMPLE SET OF TEST WING RADAR RESOURCES
(For Example Radar Allocation Problem)

g	TAV_g	s	Name	Description
1	4	1-5	A20FPQ16-XX	FPQ Tracking Radar Systems
2	1	6-7	A3MPS19-XX	MPS19 Tracking Radar Systems
3	3	8-10	A13ASADSX	SADS Threat Radar Systems
4	3	11-15	A30XXXXXX	Mix of Mobile and Simulated Threat Radar Systems
5	2	16-18	B1XWESTXX	WEST Threat Radar Systems
6	2	19-22	A1XXXXXXX	NIKE, HAWK and WEST Radar Systems

On the next page, Figure 5.1 depicts both "general" and "specified" radar resource requirements for the same set of 17 test missions used in the aircraft allocation example problem. As in that example, test engineers may submit requests for a particular radar "s" from general category "g", or for any radars within "g" if particular radars are not needed, or both. For example, TM1 specifically requests the use of radar #1, along with two additional radars of the same general type from general category 1.

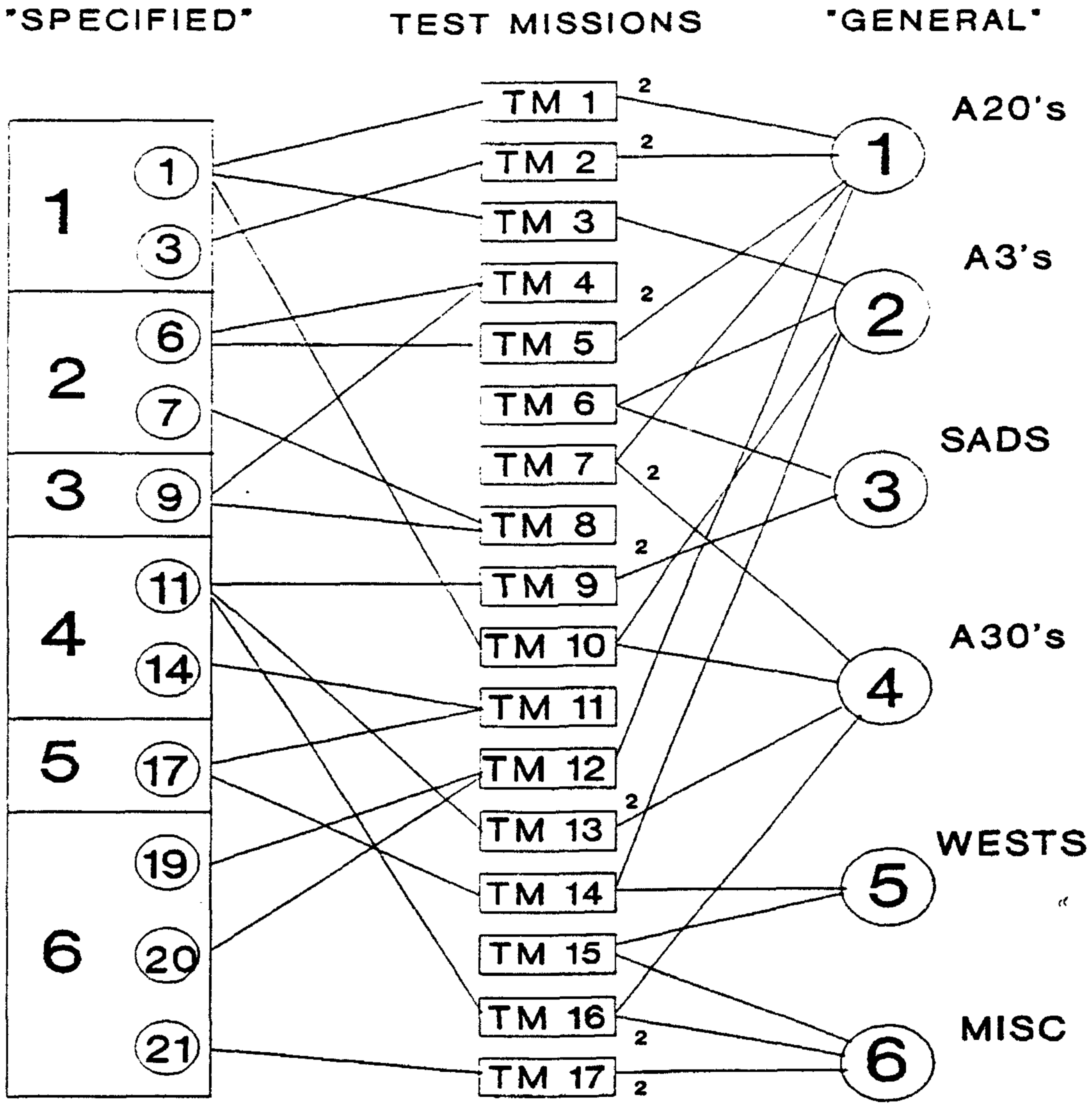

Figure 5.1 "General" and "Specified" Radar Resource Requirements (Radar Allocation Example)*

*Unless otherwise noted next to each requested test mission, requests from each general radar category are for a single radar.

Again, as in the aircraft example problem, the overall goal is to schedule as many of the 17 test missions as possible for a specific day. Hence, the main objective in the scheduling process is to:

$$MAX\ Z = \sum_{t=1}^{5} \sum_{j=1}^{17} x_{tj} \tag{5.1}$$

To accomplish the above objective each "specified" radar resource requirement, as depicted in Figure 5.1, was first placed in tabular format as shown in Table 5.2 on the next page. Total requirements for each specified category "s" or $\sum REQ_{sj}$'s are tallied across each row and found along the right-hand side of the table. A scheduling conflict is unavoidable when this sum is greater than four or five (depending on type radar) since tracking radars can support, at most, five missions a day while all others can support up to four.

TABLE 5.2

"SPECIFIED" RADAR REQUIREMENTS (REQ_{sj})
(For Example Radar Allocation Problem)

Test Mission j

s	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	$\Sigma REQ_{s\cdot}$
1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
9	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2
11	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	3
14	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
17	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	2
19	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
$\lvert S_j \rvert$	1	1	1	2	1	1	1	2	1	1	2	2	1	1	1	1	1	

Looking across the rows in the Table 5.2, one can see that no immediate conflicts exist between the 17 test missions requesting "specific" radar resources since no sums are greater than four.

The following "specified" constraints from the Radar Allocation For-ulation ensure that if a test is scheduled within a period t, then its requested radar are not assigned to any other missions within that same period:

$$\sum_{j=1}^{17} (REQ_{sj} \cdot x_{1j}) \le 1, \qquad \forall\, s \in STR \tag{5.2}$$

$$\sum_{j=1}^{17} (REQ_{sj} \cdot x_{tj}) \le 1, \qquad \begin{array}{l} \forall\, s \in S \\ t = 2,3,4,5 \end{array} \tag{5.3}$$

$$x_{tj} \in \{0,1\} \qquad t = 1,\ldots,5 \qquad j = 1,\ldots,17$$

In similar fashion, each "general" radar resource requirement from Figure 5.1 is placed in tabular format below.

TABLE 5.3

"GENERAL" RADAR REQUIREMENTS (REQ_{gj})
(For Example Radar Allocation Problem)

Test Mission j

g	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	ΣREQ_{gj}
1	3	3	1	0	2	0	1	0	0	1	0	1	0	0	0	0	0	12
2	0	0	1	1	1	1	0	1	0	1	0	0	0	1	0	0	0	7
3	0	0	0	1	0	1	0	1	2	0	0	0	0	0	0	0	0	5
4	0	0	0	0	0	0	2	0	1	1	1	0	3	0	0	2	0	10
5	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	0	4
6	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2	2	7
$\lvert G_j \rvert$	3	3	2	2	3	2	3	2	3	3	2	3	3	3	2	4	2	

In Table 5.3, specified radar requirements are included within each test mission's general radar requirement count. Given the totals for each requested mission, the following "general" constraints from the radar formulation need to be applied:

$$\sum_{j=1}^{17} (REQ_{gj} \cdot x_{1j}) \leq TAV_g, \qquad \forall g \in GTR \qquad (5.4)$$

$$\sum_{g \notin GTR} \sum_{j \in J} (REQ_{gj} \cdot x_{1j}) = 0 \qquad (5.5)$$

$$\sum_{j=1}^{17} (REQ_{gj} \cdot x_{tj}) \leq TAV_g, \qquad \begin{array}{l} \forall g \in G \\ t = 2,3,4,5 \end{array} \qquad (5.6)$$

$$x_{tj} \in \{0,1\} \qquad t = 1,\dots,5 \qquad j = 1,\dots,17$$

Finally, to ensure that a test mission is not scheduled for more than one time period, the last set of constraints found in the Radar Allocation Formulation must be applied:

$$\sum_{t=1}^{5} x_{tj} \le 1, \qquad j = 1,\ldots,17 \tag{5.7}$$

$$x_{tj} \in \{0,1\} \qquad t = 1,\ldots,5 \qquad j = 1,\ldots,17$$

Using the LINDO (Linear, Interactive and Discrete Optimizer) linear program solver, an optimal solution to this example radar allocation problem was generated (see Appendix B) and is summarized below:

$$\begin{aligned} Z_{max} = 15 \quad \text{with } x_{1j} &= 1 \text{ for } j = 3 \\ x_{2j} &= 1 \text{ for } j = 1,\ 6,\ 7,\ 15 \\ x_{3j} &= 1 \text{ for } j = 10,\ 16 \\ x_{4j} &= 1 \text{ for } j = 5,\ 13,\ 17 \\ x_{5j} &= 1 \text{ for } j = 2,\ 8,\ 9,\ 11,\ 12 \\ \text{and } x_{tj} &= 0 \text{ for } j = 4,\ 14 \end{aligned}$$

Therefore, mission 3 can be allocated all its requested radars in period 1, missions 1, 6, 7, and 15 in period two, missions 10 and 16 in period 3, missions 5, 13, and 17 in period 4, and missions 2, 8, 9, 11, and 12 in period 5. Only missions 4 and 14 could not be supported in any of the five periods.

For this example, other optimal distributions of radars to test missions, within the five different time periods, may be possible. However, in no case will the maximum number of fully allocated missions or Z_{max} exceed 15.

Note, in the previous example, the maximum number of missions supported by the aircraft-fleet is less than the number above. Therefore, Z_{max} for aircraft or 13, is the more restrictive upper bound on the number of missions that could be supported in this set.

6. *Range Area Model Formulation*

6.1 Allocating Range Areas

The objective of the following mathematical model is to determine the maximum number of test missions, of a given set, that can be allocated their requested **range area** resources without violating any general or range area specific assumptions.

6.1.1 Range Area Specific Modeling Assumption.

Several range area specific modeling assumptions were made in the Range Area Allocation Formulation.

As in previous formulations, this first assumption provides a convenient means of allowing each range area the ability to support up to a realistic number of missions on any given day. Given the standard length of a test mission varies between 1.5 and 3.0 hours, and also, given a normal day in which no more than one 3.0 hour mission (ie., Flutter or Amraam mission) will be conducted, up to six 1.5 hour missions can be supported by a range area, in addition to the one 3.0 hour mission, in a 12 hour time frame. Therefore, each testing day is broken up into seven non-overlapping time periods in which each range area can support no more than one mission per period for a total of, at most, seven missions in a day.

Differing slightly from the previous two formulations, all requests for range areas must be specified except for range areas within the W151 overwater range area blocks (see Appendix A Table A.5). This exception accommodates short-duration training missions which do not need a specific range area to train within, but, desire ranges close to Eglin.

6.1.2 Radar Specific Parameters. The following parameter is specific to range areas and is in addition to the general parameters listed in chapter 3:

W151 = Set of range subareas located within W151 overwater test area block (See Appendix A, Table A.6).

6.1.3 Range Area Allocation Formulation.

Objective Function:

$$\sum_{t \in T} \sum_{j \in J} x_{tj} \tag{6.1}$$

Subject To:

$$\sum_{j \in J} (REQ_{sj} \cdot x_{tj}) \le 1, \qquad \forall s \in S, \quad t = 1, \ldots, 7 \tag{6.2}$$

$$\sum_{g \in W151} \sum_{j \in J} (REQ_{gj} \cdot x_{tj}) \le \sum_{g \in W151} TAV_g, \qquad t = 1, \ldots, 7 \tag{6.3}$$

$$\sum_{t \in T} x_{tj} \le 1, \qquad \forall j \in J \tag{6.4}$$

$$x_{tj} \in \{0,1\} \qquad t = 1, \ldots, 7 \qquad j = 1, \ldots, J$$

The above constraints are similar to those found in the previous two model formulations. Constraint 6.2 ensures that the "specified" range areas allocated a mission are not allocated to other missions in the same period. Constraint 6.3 ensures the number of "general" areas allocated from the W151 overwater range area blocks do not exceed the number available in each period.

Constraint 6.4, as in previous formulations, ties the formulation together by limiting each test mission to one of seven time periods, thus, allowing each range area the capability of supporting up to seven different missions in a testing day. It also prevents partial allocation of range areas to test missions when any or all range areas requested by the mission cannot be allocated. In such instances, a test mission would not be assigned a time period, and thus, be listed as non-scheduled.

6.2 Allocating Range Areas (Example Problem)

The following example illustrates the use of the range area allocation model in determining the maximum number of test missions, in a given set, that can be allocated their requested range areas in a seven-period day. No other Test Wing resources are considered in the allocation process.

Table 6.1 below lists the TW range areas considered in this example problem. Note that the table is similar to those found in Appendix A and that it's broken up into general "G" and specified "S" sets of range area categories with each individual range area "s" belonging to a general group "g".

TABLE 6.1

SAMPLE SET OF TEST WING RANGE AREAS
(For Range Area Allocation Example Problem)

g	TAV_g	s	Name	Description
1	3	1 2 3	W151A1 W151A3 W151A5	OVERWATER TEST AREAS
2	3	4 5 6	W151A2 W151A4 W151A6	
3	4	7 8 9 10	W470B W470C W470D W470E	TYNDALL AFB TRAINING AREAS
4	1	11	B70	AIR-TO-GROUND TEST AREA
5	3	12 13 14	C52A C52C C52N	C52 BOMB TEST AREAS
6	1	15	C62	AIR-TO-GROUND TEST AREA

Figure 6.1 depicts both the general and specified range areas requested by the same set of 17 test missions used in the previous two chapter's example problems. Test mission 1 (TM 1) for example, is specifically requesting areas 1 and 3 from general overwater category 1. TM 2, on the other hand, is specifically requesting area 9 from general extended overwater category 2, along with all the areas found in general overwater category 1. Hence, these two missions are directly competing against each other for some of the same range areas found in general category 1.

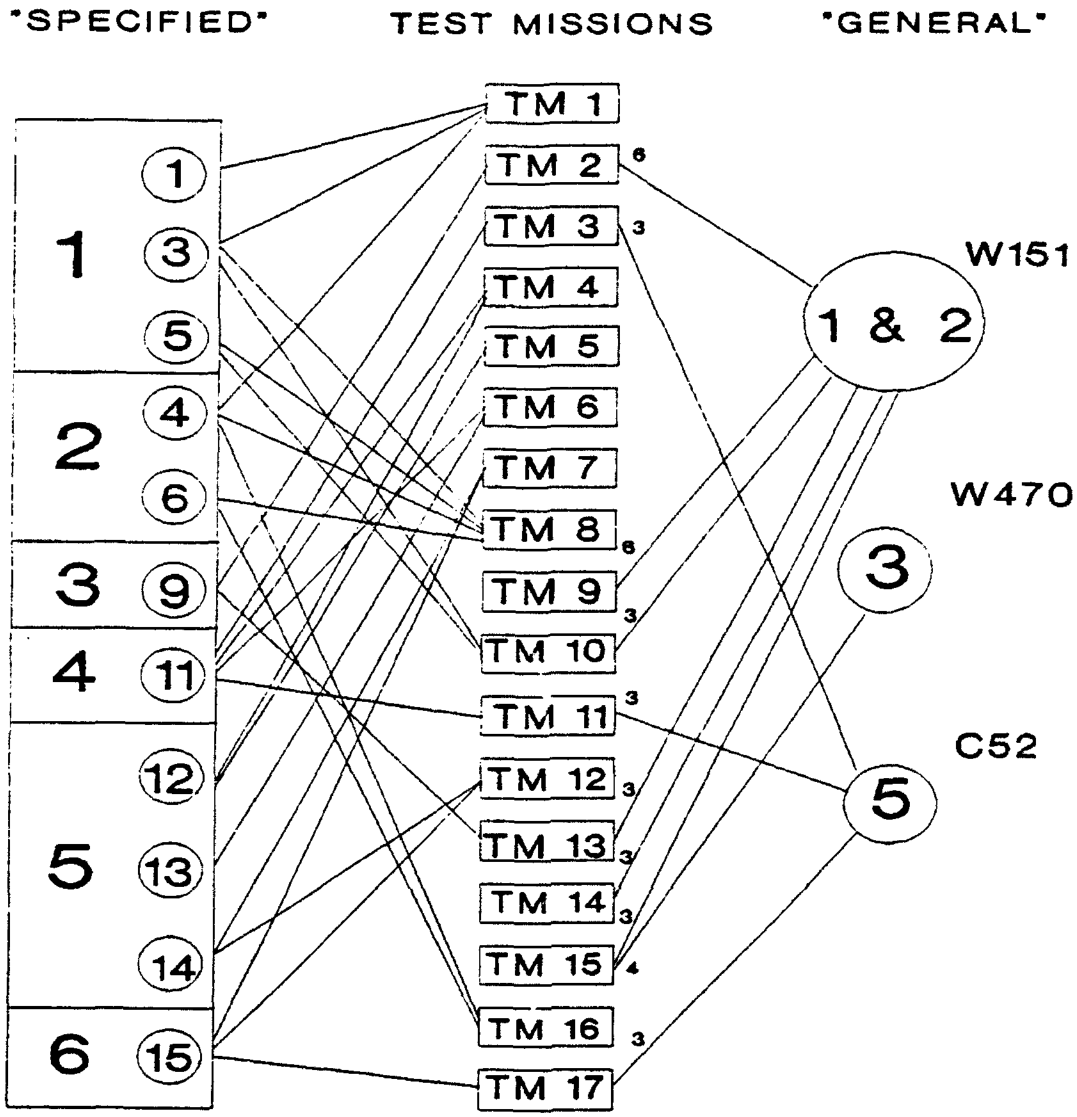

Figure 6.1 "General" and "Specified" Range Area Requirements (Range Allocation Example)*

* The number of subareas requested from each general range area block are noted next to each test mission.

Again, as in previous example problems, the overall goal is to schedule as many of the 17 test missions as possible for this specific day.

Hence, the main objective in the scheduling process is:

$$MAX\ Z = \sum_{t=1}^{7} \sum_{j=1}^{17} x_{tj} \tag{6.1}$$

Each "specified" range area requested by the 17 test missions is shown in Table 6.2 on the next page. Note that when a "general" block of range areas is requested, all subareas within that block are specifically being requested, and thus, are included in the table. Total requirements for each specified category "s" or $\sum REQ_{sj}$'s are tallied across each row and found along the right-hand side of the table. A scheduling conflict is unavoidable when this sum is greater than seven since each range area can support at most, seven missions in a day.

TABLE 6.2

"SPECIFIED" RANGE AREA (REQ_{sj})
(For Range Area Allocation Example Problem)

Test Mission j

s	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	$\sum REQ_{sj}$
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3
4	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	3
5	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2
9	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	3
11	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	4
12	0	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	1	5
13	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	4
14	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	1	5
15	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	3
$\lvert s_j \rvert$	3	1	4	2	1	2	2	4	0	2	4	2	1	0	1	2	4	

Looking across each row one can see that many of the test missions are competing for the same range areas. However, in no case are more than 7 missions requesting a single area. Therefore, no immediate conflicts exist between the 17 test missions in requesting "specified" range areas.

The following "specified" constraints from the Range Area Allocation Formulation ensure that if a mission is scheduled within a period t, then its requested range areas are not assigned to any other missions within that same period:

$$\sum_{j=1}^{17} (REQ_{sj} \cdot x_{tj}) \leq 1, \qquad \begin{array}{l} s \in S \\ t = 1,\ldots,7 \end{array} \qquad (6.2)$$

$$x_{tj} \in \{0,1\} \qquad t = 1,\ldots,7 \qquad j = 1,\ldots,17$$

In similar fashion, the "general" range areas requested by the 17 test missions are laid out in Table 6.3 on the next page. Recall in the model assumptions, that general requests for subareas may only be made for subareas within the W151 general block areas. "Specified" requests from these areas must be included in the total "general" requirement count for each test mission j.

TABLE 6.3

"GENERAL" RANGE AREA REQUIREMENTS (REQ_{gj})
(For Range Area Allocation Example Problem)

Test Mission j

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
g 1&2	3	6	0	0	0	0	0	4	6	5	0	0	3	3	3	2	0	35 ΣREQ_{gj}
$\lvert G_j \rvert$	1	2	2	2	1	2	2	2	1	1	2	2	2	1	2	1	2	

Looking across the row one can see that no direct conflict exists in allocating subareas found in W151 overwater range area blocks 1 and 2 since 42 general allocations (6 subareas over 7 periods) of W151 subareas can be made on any given day.

To ensure that number of general range areas allocated in each period does not exceed the number available, the following "general" constraint from the range area formulation must be satisfied:

$$\sum_{g=1}^{2} \sum_{j=1}^{17} (REQ_{gj} \cdot x_{tj}) \le \sum_{g=1}^{2} TAV_{g}, \qquad t = 1, \ldots, 7 \qquad (6.3)$$

$$x_{tj} \in \{0,1\} \qquad t = 1, \ldots, 7 \qquad j = 1, \ldots, 17$$

Finally, to ensure that a test mission is not scheduled for more than one period in a day, the last set of constraints from the Range Area Allocation Formulation must be satisfied.

$$\sum_{t=1}^{7} x_{tj} \leq 1, \qquad j = 1,\ldots,17 \qquad (6.4)$$

$$x_{tj} \in \{0,1\} \qquad t = 1,\ldots,7 \qquad j = 1,\ldots,17$$

Using the LINDO (Linear, Interactive and Discrete Optimizer) linear program solver, an optimal solution to this example range area allocation problem was generated (see Appendix B) and is summarized below:

Z_{max} = 17 with x_{1j} = 1 for j = 6,8,14 x_{5j} = 1 for j = 4,10

x_{2j} = 1 for j = 5,9,12 x_{6j} = 1 for j = 2,11

x_{3j} = 1 for j = 7,16 x_{7j} = 1 for j =1,13,17

x_{4j} = 1 for j = 3,15

Thus, all test missions j can be fully allocated their requested range areas in a seven-period day.

As in the previous example problems, other optimal distributions of range areas to test missions may be possible. However, in no case will the maximum number of fully allocated test missions ever exceed the value of Z_{max} or in this case 17.

Note from the previous two problem solutions, that aircraft resources are the most constraining of the three resources considered for this test mission set. Therefore, Z_{max} for aircraft or 13, is the upper bound on the number of test missions in this set, that can be allocated all their requested TW aircraft, radar, and range area resources. Thus, Eglin's test range capacity for these 17 missions is estimated to be no better than 13.

7. *Computational Testing and Analysis*

This chapter examines how each resource allocation model was applied and tested using actual TW data. A discussion of the computer software used, problems encountered, and an analysis and summary of results for each model formulation are presented.

7.1 *Resource Model Application*

Each resource allocation model described in the previous chapters was tested using data supplied by 3246 TW Plans and Programs (XPP) office. The data, taken from the Management Information System (MIS) of RESOMS, spans a three week period in February 1992. This period was chosen due to the high volume of test mission requests and associated non-scheduled information that normally typifies such times of the year (21). The data was comprised of all open-air missions requesting range resources for specified days in the three week period. Also included in this data was whether or not a mission was scheduled, non-scheduled, or canceled during this time frame (see Appendix D and G for input data).

7.1.1 GAMS (General Algebraic Modeling System). GAMS was the programming language used to model each resource allocation formulation described in the previous chapters.

Offering a full complement of mathematical relationships that can concisely represent complex algebraic relationships in a simple, easily modifiable manner, it was ideally suited for modeling each resource allocation formulation (see Appendix C for overall GAMS source code).

7.1.2 GAMS/ZOOM (Zero/One Optimization Method).

Currently, the most accessible IP solver suitable for use with GAMS is called GAMS/ZOOM. An adaptation of ZOOM, this problem solver uses a combination of complementing solution approaches to systematically find solutions to medium-sized problems such as those pertaining to each resource allocation model. With a solution tolerance level set to .05 for each model, GAMS/ZOOM was quickly able to find feasible integer solutions that fell within 5% of the upper bound LP relaxation solutions for each resource allocation problem. On a Digital Equipment Corporation (DEC) VAX 8550 with 64 megabytes of main memory, the average cpu time was less than five minutes for each model and given set of TW data.

7.2 Problems Encountered

A few problem situations were encountered before and during the testing process. These areas had a direct effect on each model's outcome and are addressed here for future reference.

7.2.1 Training Missions. Aircraft used on multiple short-duration training missions do not fit the "maximum of two missions a day" assumption made in the aircraft formulation. In many instances, the same aircraft used on one training mission was repeatedly used up to two or three more times on other training missions throughout the day (21). Hence, their input data had to be modified slightly to reflect this usage without invalidating the Aircraft Model. To prevent multiple short-duration training missions from being allocated a disproportionate number of available TW aircraft in either of the two periods of the Aircraft Model, only the first in a string of related training missions could request a TW aircraft (reflected in the input data). In this manner, the "general" aircraft allocated to training missions, could be accounted for in the allocation process, while all training missions show up as being scheduled in the model results.

7.2.2 Alternate Test Mission Requests. As briefly discussed in Chapter 1, a number of Alternate Test Missions are commonly requested and scheduled on any particular day. Current TW procedure is to list these missions as scheduled, even though they are not allocated any resources, but instead, stand-by to use resources allocated to a primary mission in the event that it cancels. Unless deleted from the input data used to test each resource allocation model, the presence of these missions causes a discrepancy between the capacity calculated by each model and the number reported as "actually scheduled". For in effect, Alternate Missions "double book" an assortment of resources which invariably prevents a number of other missions from being scheduled by the three models. Therefore, a true indication of range capacity cannot be determined unless Alternate Missions are excluded from the TW data sets.

In the TW data sets provided, no distinctions were made between Alternate Mission and Backup Mission data. Both types of missions were simply listed as canceled Backup Missions in each of the data sets. Hence, to ensure all Alternate Mission requests were excluded from a given set of TW data, it was necessary to exclude all missions listed as canceled Backup Missions.

7.3 Analysis and Summary of Results

The following sections report results obtained in testing each resource allocation model. Two sets of TW data were used in this process: a complete set of all missions requested including Backup and Alternate Missions, and a modified set of missions requested that excluded these types of missions from each data set (see Appendix D).

In the testing process, the number of zero/one variables used by each model noticeably affected their solution times. As this number increased from the Aircraft to the Radar to the Range Area Model (due to the increase in time periods specified), the time required to find a feasible solution in each instance also increased. Nevertheless, total solution time for all three models and a given data set never took more than approximately 10 minutes of cpu time on a VAX 8550 computer. This however, does not necessarily mean that other data sets can also be solved in such an expedient manner. Larger or more complicated data sets may take considerably longer to solve. A tighter tolerance criteria specified for the solution could likewise slow down the process (refer back to 7.1.2).

Note that, since mission priorities were not modeled, no correlation exists between missions that were actually non-scheduled and those non-scheduled by the each allocation model (see Appendix G and H).

7.3.1 Aircraft Allocation Model. Table 7.1 on the following page, displays results summarizing the Aircraft Model's performance when tested with data sets that included Backup and Alternate Test Mission requests. In four instances highlighted in the table, the number of missions classified as scheduled by the TW exceeded the "upper bound" number of missions determined by the Aircraft Model.

TABLE 7.1

AIRCRAFT ALLOCATION MODEL RESULTS
(Using Complete Mission Data Sets)

Date	Total # of Missions	Total # of NS Missions	Total # Scheduled	Aircraft Model Results	Diff
03Feb	66	10	56	65	9
04Feb	70	13	57	65	8
05Feb	72	6	66	65	*-1
06Feb	74	7	67	66	*-1
07Feb	70	9	61	66	5
10Feb	75	4	71	71	0
11Feb	80	5	75	72	*-3
12Feb	83	11	72	78	6
13Feb	87	11	76	82	6
14Feb	80	10	70	75	5
18Feb	68	7	61	62	1
19Feb	81	4	77	77	0
20Feb	71	4	67	64	*-3
21Feb	72	7	65	66	1

On the next page, Table 7.2 summarizes the test results after the data sets were modified to exclude all canceled test missions requests, the majority of which were Backup and Alternate Mission cancellations. By doing so, the Aircraft Model correctly reported an upper bound on missions actually scheduled. On average, the model allocated an additional 4.9 missions more than what was actually scheduled.

TABLE 7.2

AIRCRAFT ALLOCATION MODEL RESULTS
(Using Reduced Mission Data Sets)

Date	Total # of NC Missions	Total # of NS Missions	Total # Scheduled	Aircraft Model Results	Diff
03Feb	57	10	47	56	9
04Feb	56	13	43	53	10
05Feb	54	6	48	51	3
06Feb	56	7	49	50	1
07Feb	46	9	37	43	6
10Feb	58	4	54	54	0
11Feb	60	5	55	57	2
12Feb	63	11	52	63	11
13Feb	67	11	56	64	8
14Feb	55	10	45	52	7
18Feb	48	7	41	44	3
19Feb	56	4	52	54	2
20Feb	52	4	48	49	1
21Feb	50	7	43	48	5

In comparing the two aircraft tables, Canceled Mission data significantly affected the perceived quality of the model outcome. Therefore, given that a large proportion of canceled mission data is made up of Alternate Missions cancellations, then the Aircraft Allocation Formulation, as modeled, appears to generate a legitimate upper bound on the number of missions that could possibly be scheduled in any of the TW data sets.

7.3.2 ***Radar Allocation Model.*** Below in Table 7.3, are results summarizing the Radar Allocation Model's performance using the same complete sets of data used in testing the Aircraft Model. In only one case, highlighted below, did the model's upper bound on range capacity fail to equal or exceed the number of missions classified as scheduled by the TW.

TABLE 7.3

RADAR ALLOCATION MODEL RESULTS
(Using Complete Mission Data Sets)

Date	Total # of Missions	Total # of NS Missions	Total # Scheduled	Radar Model Results	Diff
03Feb	66	10	56	66	10
04Feb	70	13	57	65	8
05Feb	72	6	66	69	3
06Feb	74	7	67	69	2
07Feb	70	9	61	70	9
10Feb	75	4	71	75	4
11Feb	80	5	75	74	*-1
12Feb	83	11	72	78	6
13Feb	87	11	76	81	5
14Feb	80	10	70	74	4
18Feb	68	7	61	64	3
19Feb	81	4	77	77	0
20Feb	71	4	67	67	0
21Feb	72	7	65	69	4

In Table 7.4 the data sets have again been modified to exclude all canceled test mission requests. As a result, the Radar Model was able to generate upper bounds, that equaled or exceeded the number of actually scheduled missions in all 14 TW data sets. On average, the difference between the upper bound and the number actually scheduled was 5.9 missions.

TABLE 7.4

RADAR ALLOCATION MODEL RESULTS
(Using the Reduced Mission Data Sets)

Date	Total # of NC Missions	Total # of NS Missions	Total # Scheduled	Radar Model Results	Diff
03Feb	57	10	47	57	10
04Feb	56	13	43	54	11
05Feb	54	6	48	53	5
06Feb	56	7	49	54	5
07Feb	46	9	37	46	9
10Feb	58	4	54	58	4
11Feb	60	5	55	57	2
12Feb	63	11	52	62	10
13Feb	67	11	56	64	8
14Feb	55	10	45	51	6
18Feb	48	7	41	47	6
19Feb	56	4	52	54	2
20Feb	52	4	48	49	1
21Feb	50	7	43	47	4

As in the Aircraft Model, canceled mission data significantly affected the Radar Model's outcome, again suggesting that a large portion of this data was possibly made up of Alternate Mission cancellations. With this input data modification, the Radar Model seemed to generate legitimate upper bounds on the number of missions that could possibly be scheduled in any of the TW data sets.

7.3.3 ***Range Area Allocation Model.*** Below in Table 7.5 are results summarizing the Range Area Allocation model's performance using the same complete sets of TW data previously used by the other two models. Again, as in the other models, the Range Area Model generated some upper bounds that did not equal or exceed the number of missions classified as scheduled by the TW.

TABLE 7.5

RANGE AREA ALLOCATION MODEL
(Using the Complete Mission Data Sets)

Date	Total # of Missions	Total # of NS Missions	Total # Scheduled	Range Area Model Results	Diff
03Feb	66	10	56	65	9
04Feb	70	13	57	60	3
05Feb	72	6	66	67	1
06Feb	74	7	67	65	*-2
07Feb	70	9	61	69	8
10Feb	75	4	71	72	1
11Feb	80	5	75	72	*-3
12Feb	83	11	72	75	3
13Feb	87	11	76	82	6
14Feb	80	10	70	72	2
18Feb	68	7	61	64	3
19Feb	81	4	77	72	*-5
20Feb	71	4	67	60	*-7
21Feb	72	7	65	67	2

In Table 7.6, the test data was once again modified to excluded all canceled test mission requests. However, unlike the other two model results, the Range Area Model was again unable to generate upper bounds that equal or exceed all numbers of actually scheduled missions. Although the model improved markedly over results found in Table 7.5, it still failed to provide upper bounds to the number of scheduled missions in two instances highlighted below.

TABLE 7.6

RANGE AREA ALLOCATION MODEL
(Using the Reduced Mission Data Sets)

Date	Total # of NC Missions	Total # of NS Missions	Total # Scheduled	Range Area Model Results	Diff
03Feb	57	10	47	56	9
04Feb	56	13	43	52	9
05Feb	54	6	48	51	3
06Feb	56	7	49	52	3
07Feb	46	9	37	46	9
10Feb	58	4	54	58	4
11Feb	60	5	55	54	* **-1**
12Feb	63	11	52	61	9
13Feb	67	11	56	65	9
14Feb	55	10	45	53	8
18Feb	48	7	41	48	7
19Feb	56	4	52	54	2
20Feb	52	4	48	47	* **-1**
21Feb	50	7	43	48	5

As in previous models, canceled mission data affected the Range Area Model's outcome. Without its inclusion the model performed significantly better, however, not well enough in all cases as noted in Table 7.6. Hence, the Range Area Allocation Formulation, as presently modeled, should not be used to help specify an upper bound on the number of missions that can possibly be scheduled in a given set.

One reason for its demise, may possibly be attributed to the number of time periods specified in the formulation. For example, if the number of periods is increased from seven to eight, the model's estimate of capacity exceeds the number of scheduled missions in every data set tested. However, with eight time periods per range area, the model is also able to support all the requested missions in every set, thus generating seemingly unrealistic results. Therefore, in comparing results when different numbers of periods are specified, it may be that some range areas can support eight missions a day while others can support only seven.

7.4 Final Result

On the next page, Figure 7.1 displays the final overall test results for the modified sets of TW data. This figure consolidates results from the Aircraft and Radar Allocation Models and compares them against the actual numbers of missions scheduled. In addition, total missions available for scheduling (maximum daily capacity) is provided in the background for reference. Note that the consolidated model results simply represents the least of the two upper bounds determined by each resource allocation model and given set of TW data.

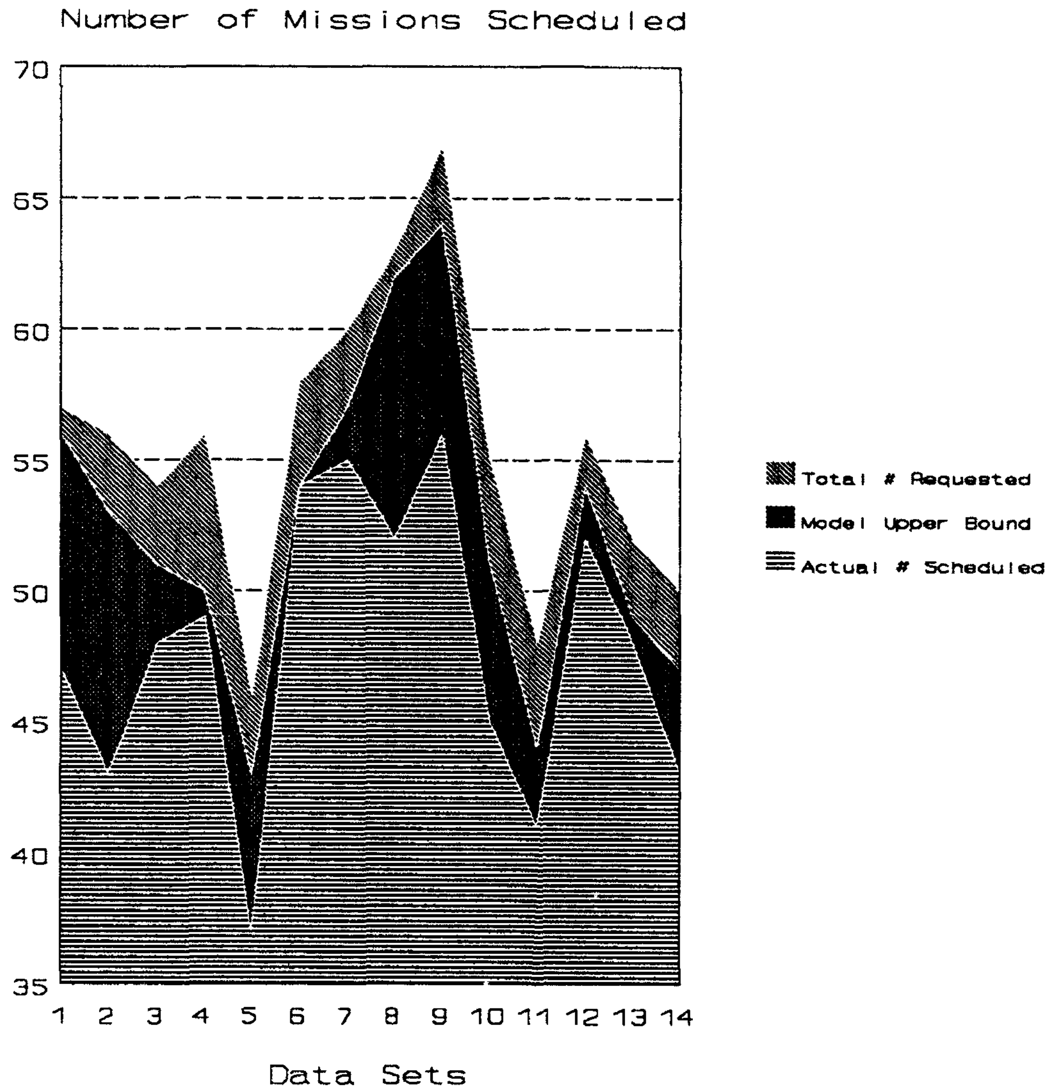

Figure 7.1 Upper Bound Estimates on Range Capacity vs Actual Numbers of Missions Scheduled.

As depicted above, at no time were either the Aircraft or Radar Model able to allocate resources to every test mission within a given data set. However, for the most part, they were able to generate bounds close to what was actually scheduled by the TW. Hence, they seem to provide legitimate upper bounds for each set of TW data. Also, note that the darken portion above the number of missions actually scheduled represents an estimate of the number of additional missions these two resources were capable of supporting, and not of excess capacity. For instance, if the set of scheduled missions on any given day includes a few high priority missions that require a large number of aircraft, the model results may indicate that more missions (possibly requiring fewer aircraft per mission) could have been scheduled if priorities were ignored.

8. Conclusions and Recommendations

Eglin's Test Range Capacity is not a number that one simply can put their finger on and state is Eglin's overall testing capability, but rather a wide ranging variable that changes daily depending upon the number and types of test missions being requested. Developing a method to determine this daily number was the main focus of this study.

8.1 Conclusions

This study shows that it's possible to mathematically model the allocation of TW resources to test missions using zero/one integer programming. In such models, each test mission in a given set, is restricted to one of a number of distinct, non-overlapping time periods. At the same time, each modeled resource can only be allotted to one test mission in each of these periods. Hence, to be scheduled, a test mission must be able to receive all it's requested resources in one of the given periods. In maximizing the number of missions scheduled, a zero/one decision variable assigned to each test mission in the set, signifies whether or not a mission was successful in this endeavor.

The number of periods specified in the above manner, determines the number of times each resource could be allocated in a day, thus allowing present operational usage of range resources to be accurately modeled. Therefore, with two time periods specified in the Aircraft Model, each TW aircraft was limited to supporting no more than two separate test missions per day, while, TW radars and range areas were restricted to five and seven test missions respectively, due to the number of time periods specified in their models.

The maximum number of missions that possibly could be scheduled in a given set (range capacity) could then be estimated by each of the three resource allocation models. The lowest number of scheduled missions produced by one of the models then becomes the upper bound on range capacity. No additional missions beyond this number can be scheduled due to the non-availability of one of the modeled resources.

Using the above approach, the three resource allocation models developed in this study fared reasonably well in actual testing. However, on two of fourteen days of test data, the Range Area Model gave solution values which did not equal or exceed the number of missions actually scheduled. Therefore, in its present form, it should not be used to help establish an upper bound on range capacity. On the other hand, the Aircraft and Radar Models, produced results that appear to be legitimate upper bounds for the given TW data sets. However, more testing needs to be done to confirm the validity of the modeling assumptions inherent in these models, as well as, to determine if other situations, not presently addressed, need to be included in either model formulation.

One notable problem that surfaced while testing the Aircraft Allocation Model concerned training mission requirements. It was discovered that training missions do not follow the "two missions" a day assumption made in the model formulation, hence, their inclusion in the mission data sets produced some erroneous results for the Aircraft Model. However, by manipulating the data so that only the first in a string of training missions was allocated a TW aircraft, the problem seems to be solved. Nevertheless, further testing of the Aircraft Model is necessary in order to verify this solution approach.

One problem that affected all three models during the testing phase, involved Alternate Mission requests in the mission data sets. Although regarded as "scheduled" missions by the TW, these missions were not allocated any resources and thus, should not be included in the mission data sets used to test each resource allocation model. However, in eliminating these missions from the TW data provided, it was not possible to distinguish whether or not a mission was an Alternate or a Backup. Consequently, all Backup missions were also eliminated from each set of TW data. Therefore, additional testing using data sets that exclude only Alternate missions is recommended.

Hence, although the Aircraft and Radar Allocation Models appear to accurately estimate daily range capacity, further testing is recommended in order to verify their applicability in all situations.

8.2 Additional Recommendations

In their present form, both the Aircraft and Radar Allocation models could be used as an aid to schedulers or decision makers in the scheduling process. The partitioning of test missions into different time periods throughout the day could help in sequencing or arranging missions so that the majority in a given set, can be scheduled. It can also be used to identify missions (those non-scheduled by either model) that conflict with others within the set so that appropriate action can be taken. In addition, the models can also be used to forecast upcoming workload capabilities so that test engineers can make a more informed decision on whether or not to request a particular day for testing.

Although the Aircraft and Radar Allocation Models produce reasonable upper bound values on daily range capacity, a single model that includes these two resource categories and possibly several others, should be developed. Such a model would produce a more refined upper bound on range capacity, thus, provide a sharper picture of test range capabilities, as well as, information on how resources interact within the allocation process.

To determine true range capacity, a model that considers the allocation of every range resource is needed. However, because there's no practical way of getting timely solutions from such an all-inclusive (resource) model a lesser model that considers only a few of the most schedule-limiting TW resources, as discussed above, is more appropriate and probably just as effective.

Besides refining daily range capacity estimates, a multi-resource model could possibly be used to aid in the daily scheduling process. In addition, test mission priorities could be incorporated by assigning a cost coefficient (ranking) to each test mission in the model's objective function. Thus, the effect of mission priorities on the number of scheduled missions could be studied. Additionally, the difference between the upper bounds generated by such a model and the number of missions actually scheduled by the TW could also be studied to see if such a difference would equate to excess capacity.

Ultimately, a multi-resource model would be beneficial in any future studies relating to test range expansion or consolidation of testing capabilities from elsewhere to Eglin. Given some expected or representative sets of test mission data, the model would be able to discern whether or not the capability exists to support additional testing. In the same regard, if some TW resources were eliminated a multi-resource model could be used to study what testing capabilities will be lost.

List of Acronyms

ALE-47	Piloted Aircraft Counter-Measure Ejector (Chaff Dispenser)
ALR-56	Piloted Aircraft Counter-Measure Receiver (Jamming Pod)
AMRAAM	Advance Medium Range Air-to-Air Missile
ATARS	Advanced Tactical Air Reconnaissance System
BASES	Beam Approach Seeker Evaluation System
CBU97	Cluster Bomb Unit
DUAL-POLE	Dual Polarization Mission
FPQ	Fixed Radar - Special
FPS	Fixed Radar - Search
GB	Golden Bird (Airborne Threat Simulating Aim 7 Missile)
GBCN	Internal G-Band Beacon
GPS	G-Pod Integration System
HARP	High Altitude Release Plane
I-HAWK	Improved HAWK
IDL	Improved Data Link
JTIDS	Joint Tactical Information Distribution System
MPS	Mobile Radar - Search
MSIP	Multi-Staged Improvement Program
OBEWS	On Board Electronic Warfare Simulator
OFP	Operational Flight Program
PMARBLE	Peace Marble Mission
RDIP	Radar Diagnostic Instrumentation Pod
RIP	Ripple Mission
RLGN	Ring Laser Gyro Navigation
SADS	Simulated Air Defense System
SE	Seek Eagle Mission
TEWS	Tactical Electronic Warfare System
TRR	Target Ranging Radar
TTRV	Target Tracking Radar - Vertical
WEST	Weapons Effectiveness Simulated Threat
Z-1	Software Package Onboard some Aircraft

Appendix A: 3246 Test Wing Aircraft, Radar, and Range Area Resources (as of Feb 92)

TABLE A.1

3246 TEST WING F16 AIRCRAFT RESOURCES

(3246 TW/DOS)

g = "general" resource group TAV_g = Tot # Avail in g
s = "Specific" resource within group g

g	TAV_g	s	Type	Description
1	1	1	F16A	#573 ** FLUTTER/LOADS ONLY
2	1	2	F16A	#609 ** RLG, RDIP ONLY
3	1	3	F16A	#1123 ** FLUTTER/LOADS ONLY
4	1	4	F16C	#353 ** FLUTTER/LOADS, PMARBLE ONLY
5	20	5	F16A	#551 Z-1, ANY
		6	F16A	#1269 GBCN, OBEWS, ANY
		7	F16A	#761 ADF-AMRAAM, AMRAAM, Z-1, GPS, HARP, ANY
		8	F16A	#1163 AMRAAM, CBU97, GPS, ANY
		9	F16B	#1128 Z-1, ANY
		10	F16B	#1037 GBCN, ANY
		11	F16B	#90 ANY
		12	F16B	#97 ANY
		13	F16B	#413 ANY
		14	F16B	#8101 ANY
		15	F16B	#8104 ANY
		16	F16C	#726 ANY
		17	F16C	#1154 ALR-56, DUAL-POLE, ANY
		18	F16C	#1212 GBCN, ANY
		19	F16C	#1280 AMRAAM, GPS, TOY STORE, ANY
		20	F16C	#1285 AMRAAM, GPS, TOY STORE, ANY
		21	F16C	#2000 ANY
		22	F16C	#2070 ALE-47, ALR-56, ANY
		23	F16C	#441 ALE-47, GPS, ANY
		24	F16D	#39 OBEWS, ANY

TABLE A.2

3246 TEST WING F15 AIRCRAFT RESOURCES

(3246 TW/DOS)

g	TAV_g	s	Type	Description
g = "general" resource group s = "specific" resource within g				TAV_g = Tot # Avail in g
6	1	25	F15B	#114 ** MSIP ONLY
7	15	26	F15A	#11 JTIDS, ANY
		27	F15A	#64 GB, ANY
		28	F15A	#65 ANY
		29	F15A	#80 TEWS, GPS, ANY
		30	F15A	#101 JTIDS, GPS, ANY
		31	F15B	#84 ANY
		32	F15B	#5080 MULTIPLEX POD, ANY
		33	F15C	#18 AMRAAM, MSIP, GB, GPS, ANY
		34	F15C	#542 TEWS, ANY
		35	F15C	#5126 AMRAAM, GB, GPS, ANY
		36	F15C	#468 ANY
		37	F15D	#45 AMRAAM, MSIP, GB, GPS, ANY
		38	F15D	#161 AIM 7/GB, GPS, ANY
		39	F15E	#185 TEWS, SE, IDL, RIP,BAU,ANY
		40	F15E	#188 TEWS, SE, IDL, RIP,BAU,ANY

TABLE A.3

3246 TEST WING AIRCRAFT RESOURCES - MISC.
(3246 TW/DOS)

g	TAV_g	s	Type	Description
g = "general" resource group s = "specific" resource within g				TAV_g = Tot # Avail in g
8	3	41	F111E	#115 FLUTTER, ANY
		42	F111E	#118 MIXED LOADS, ANY
		43	F111E	#58 ANY
9	5	44	F4E	#389 ANY
		45	F4E	#438 ANY
		46	F4E	#529 ANY
		47	F4E	#144 ANY
		48	F4D	#700 ANY
10	2	49	RF4C	#452 ATARS
		50	RF4C	#464 ATARS
11	1	51	C130A	#22 ANY
12	2	52	UH1N	#6617 BASES, ANY
		53	UH1N	#6626 BASES, ANY

TABLE A.4

TANKER AIRCRAFT RESOURCES (Contracted)

g	TAV_g	s	Type	Description
g = "general" resource group s = "specific" resource within g				TAV_g = Tot # Avail in g
13	1(4)	54	KC10	Each KC10 can support four test missions per period
14	1(2)	55	KC135	Each KC135 can support two test missions per period

TABLE A.5

3246 TEST WING RADAR RESOURCES

(3246 TW DOS)

g	TAV_g	s	NAME	DESCRIPTION
g = "general" resource group s = "specific" resource within g				TAV_g = Tot # Avail in g
20	4	60	A20FPQ13-17	FPQ13 TRACKING RADAR
		61	A20FPQ16-20	FPQ16 TRACKING RADARS
		62	A20FPQ16-31	
		63	A20FPQ16-32	
		64	A20FPQ16-42	
21	1	65	C10FPS16-39	
22	2	66	D3FPS16-23	
		67	D3FPS16-27	
23	1	68	A3MPS19-125	MPS19 TRACKING RADARS
		69	A3MPS19-161	
24	2	70	A3SADS4B	SIMULATED AIR DEFENSE SYSTEMS (SADS) THREAT RADARS
		71	A3SADS4C	
25	1	72	A7SADS1	
26	2	73	A11SADS11	
		74	A11SADS6	
27	3	75	A13ASADS3	
		76	A13ASADS5	
		77	A13ASADS8	
28	1	78	A17SADS2	
29	1	79	A21SADS4	
30	3	80	A30SADS8R	
		81	A30FLYCATCHER	MOBILE THREAT RADAR SYSTEMS
		82	A30ROLND	
		83	A30XM40	SIMULATION THREAT RADAR
		84	A30WEST11B	WEAPONS EFFECTIVENESS SIMULATOR THREAT (WEST) RADAR SYSTEMS
31	1	85	A21WEST15	
32	2	86	B1WEST3	
		87	B10WEST4B	
		88	B10WEST5	
33	2	89	A12WEST10	
		90	A12WEST11B	
34	2	91	A12WEST1A	
		92	A13MPQ46	MPQ46 I-HAWK RADAR
		93	A13NIKETRR	NIKE-HERCULES RANGE AND TRACKING RADARS
		94	A13NIKETTRV	

TABLE A.6

3246 TEST WING OVERWATER TEST AREAS

(3246 TW DOS)

g	TAV_g	s	Name	Description
g = "general" resource group s = "specific" resource within g				TAV_g = Tot # Avail in g
40	2	100 101	W151S1 W151S2	SHORELINE TEST AREAS
41	2	102 103	W151S3 W151S4	
42	3	104 105 106	W151A1 W151A3 W151A5	OVERWATER TEST AREAS
43	3	107 108 109	W151A2 W151A4 W151A6	
44	3	110 111 112	W151B1 W151B2 W151B4	
45	2	113 114	W151B3 W151B5	
46	2	115 116	W151C1 W151C3	
47	2	117 118	W151C2 W151C4	
48	2	119 120	W151D1 W151D3	
49	2	121 122	W151D2 W151D4	
50	5	123 124 125 126 127	W470A W470B W470C W470D W470E	TYNDALL AFB TRAINING AREAS
51	3	128 129 130	W168A W168B W168C	AIR FORCE TRAINING AREAS
52	1	131	W174	NAVY TRAINING AREAS
53	1	132	W155	
54	1	133	EWTA2	ADDITIONAL OVERWATER TEST AREAS
55	1	134	EWTA3	
56	1	135	EWTA4	
57	1	136	EWTA5	

TABLE A.7

3246 TEST WING OVERLAND TEST AREAS

(3246 TW DOS)

g	TAV_g	s	Name	Description
g = "general" resource group s = "specific" resource within g			TAV_g = Tot # Avail in g	
58	3	140 141 142	A73 A77 A78	AIR-TO-GROUND TACTICAL TRAINING AREAS
59	1	143	A79	SIDE FIRING WEAPON SYSTEM TEST AREA
60	1	144	B70	AIR-TO-GROUND TEST AREA
61	1	145	B71	BOMB TEST AREA
62	1	146	B75	AIR-TO-GROUND TEST AREA
63	1	147 148 149	C52A C52C C52N	C52 BOMB TEST AREAS
64	1	150	C53	AIR-TO-GROUND TEST AREAS
65	1	151	C62	
66	1	152	C72	

Appendix B: Linear, Interactive and Discrete Optimizer (LINDO) Solutions to Chapter 3 Example Problems

B.1 LINDO Solution to Aircraft Allocation Example Problem -

```
MAX      X11 + X12 + X13 + X14 + X15 + X16 + X17 + X18 + X19 +
         X110 + X111 + X112 + X113 + X114 + X115 + X116 + X117 +
         X21 + X22 + X23 + X24 + X25 + X26 + X27 + X28 + X29 +
         X210 + X211 + X212 + X213 + X214 + X215 + X216 + X217

SUBJECT TO
          2)   X16 + X110 <=   1
          3)   X15 + X111 <=   1
          4)   X15 + X110 <=   1
          5)   X11 + X17 + X18    <=   1
          6)   X11 + X17 + X113   <=   1
          7)   X14 + X112 + X115  <=   1
          8)   X18 + X114 <=   1
          9)   X12 + X116 <=   1
         10)   X13 + X116 <=   1
         11)   X26 + X210 <=   1
         12)   X25 + X211 <=   1
         13)   X25 + X210 <=   1
         14)   X21 + X27 + X28    <=   1
         15)   X21 + X27 + X213   <=   1
         16)   X24 + X212 + X215  <=   1
         17)   X28 + X214 <=   1
         18)   X22 + X216 <=   1
         19)   X23 + X216 <=   1
         20)   2 X11 + X12 + X13 + 2 X15 + X17 + 2 X18 + X19 +
               X110 + X113 + X116 + X117 <=   6
         21)   X11 + X12 + 3 X14 + 2 X16 + 2 X17 + X18 + X110 +
               X111 + X112 + X113 + 2 X114 + 2 X115 + X116 + X117 <=   6
         22)   X15 + X19 + X111 + X112 + X113 <=   2
         23)   X12 + X13 + X114 + X116 + X117 <=   2
         24)   X18 + X110 + X113 + X114 + X115 + X116 <=   2
         25)   2 X21 + X22 + X23 + 2 X25 + X27 + 2 X28 + X29 +
               X210 + X213 + X216 + X217 <=   6
         26)   X21 + X22 + 3 X24 + 2 X26 + 2 X27 + X28 + X210 +
               X211 + X212 + X213 + 2 X214 + 2 X215 + X216 + X217 <=   6
         27)   X25 + X29 + X211 + X212 + X213 <=   2
         28)   X22 + X23 + X214 + X216 + X217 <=   2
         29)   X28 + X210 + X213 + X214 + X215 + X216 <=   2
         30)   X11 + X21 <=   1
         31)   X12 + X22 <=   1
         32)   X13 + X23 <=   1
         33)   X14 + X24 <=   1
         34)   X15 + X25 <=   1
         35)   X16 + X26 <=   1
         36)   X17 + X27 <=   1
         37)   X18 + X28 <=   1
         38)   X19 + X29 <=   1
         39)   X110 + X210 <=   1
         40)   X111 + X211 <=   1
         41)   X112 + X212 <=   1
         42)   X113 + X213 <=   1
```

```
 43)    X114 + X214 <=    1
 44)    X115 + X215 <=    1
 45)    X116 + X216 <=    1
 46)    X117 + X217 <=    1
```

```
OBJECTIVE FUNCTION VALUE =       13.000000

VARIABLE        VALUE          REDUCED COST
     X15        1.000000        -1.000000
     X16        1.000000        -1.000000
     X18        1.000000        -1.000000
    X112        1.000000        -1.000000
    X116        1.000000        -1.000000
    X117        1.000000        -1.000000
     X21        1.000000        -1.000000
     X22        1.000000        -1.000000
     X23        1.000000        -1.000000
     X29        1.000000        -1.000000
    X210        1.000000        -1.000000
    X211        1.000000        -1.000000
    X215        1.000000        -1.000000

All other variables = 0         NO. ITERATIONS=       50
                                BRANCHES=     0 DETERM.=  1
                                BOUND ON OPTIMUM:  13
```

B.2 LINDO Solution to Radar Allocation Example Problem -

```
MAX    X11 + X12 + X13 + X14 + X15 + X16 + X17 + X18 + X19 +
       X110 + X111 + X112 + X113 + X114 + X115 + X116 + X117 +
       X21 + X22 + X23 + X24 + X25 + X26 + X27 + X28 + X29 +
       X210 + X211 + X212 + X213 + X214 + X215 + X216 + X217 +
       X31 + X32 + X33 + X34 + X35 + X36 + X37 + X38 + X39 +
       X310 + X311 + X312 + X313 + X314 + X315 + X316 + X317 +
       X41 + X42 + X43 + X44 + X45 + X46 + X47 + X48 + X49 +
       X410 + X411 + X412 + X413 + X414 + X415 + X416 + X417 +
       X51 + X52 + X53 + X54 + X55 + X56 + X57 + X58 + X59 +
       X510 + X511 + X512 + X513 + X514 + X515 + X516 + X517

SUBJECT TO
        1)   X11 + X13 + X110   <=   1
        2)   X14 + X15          <=   1
        3)   X21 + X23 + X210   <=   1
        4)   X24 + X25          <=   1
        5)   X24 + X28          <=   1
        6)   X29 + X213 + X216  <=   1
        7)   X211 + X214        <=   1
        8)   X31 + X33 + X310   <=   1
        9)   X34 + X35          <=   1
       10)   X34 + X38          <=   1
       11)   X39 + X313 + X316  <=   1
       12)   X311 + X314        <=   1
       13)   X41 + X43 + X410   <=   1
       14)   X44 + X45          <=   1
       15)   X44 + X48          <=   1
       16)   X49 + X413 + X416  <=   1
       17)   X411 + X414        <=   1
       18)   3X11 + 3X12 + X13 + 2X15 + X17 + X110 + X112 <=   4
       19)   X13 + X14 + X15 + X16 + X18 + X110 + X114    <=   1
       20)   X14 + X16 + 2X17 + X18 + 3X19 + X110 + 2X111 +
             2X112 + 3X113 + 2X114 + 2X115 + 4X116 + 2X117 =   0
       21)   3X21 + 3X22 + X23 + 2X25 + X27 + X210 + X212 <=   4
       22)   X23 + X24 + X25 + X26 + X28 + X210 + X214    <=   1
       23)   X24 + X26 + X28 + 2 X29                      <=   3
       24)   2 X27 + X29 + X210 + X211 + 3 X213 + 2 X216  <=   3
       25)   X211 + 2 X214 + X215                         <=   2
       26)   2 X212 + X215 + 2 X216 + 2 X217              <=   2
       27)   3X31 + 3X32 + X33 + 2X35 + X37 + X310 + X312 <=   4
       28)   X33 + X34 + X35 + X36 + X38 + X310 + X314    <=   1
       29)   X34 + X36 + X38 + 2 X39                      <=   3
       30)   2 X37 + X39 + X310 + X311 + 3 X313 + 2 X316  <=   3
       31)   X311 + 2 X314 + X315                         <=   2
       32)   2 X312 + X315 + 2 X316 + 2 X317              <=   2
       33)   3X41 + 3X42 + X43 + 2X45 + X47 + X410 + X412 <=   4
       34)   X43 + X44 + X45 + X46 + X48 + X410 + X414    <=   1
       35)   X44 + X46 + X48 + 2 X49                      <=   3
```

```
36)   2 X47 + X49 + X410 + X411 + 3 X413 + 2 X416   <=   3
37)   X411 + 2 X414 + X415                          <=   2
38)   2 X412 + X415 + 2 X416 + 2 X417               <=   2
39)   3X51 + 3X52 + X53 + 2X55 + X57 + X510 + X512  <=   4
40)   X53 + X54 + X55 + X56 + X58 + X510 + X514     <=   1
41)   X54 + X56 + X58 + 2 X59                       <=   3
42)   2 X57 + X59 + X510 + X511 + 3 X513 + 2 X516   <=   3
43)   X511 + 2 X514 + X515                          <=   2
44)   2 X512 + X515 + 2 X516 + 2 X517               <=   2
45)   X11 + X21 + X31 + X41 + X51                   <=   1
46)   X12 + X22 + X32 + X42 + X52                   <=   1
47)   X13 + X23 + X33 + X43 + X53                   <=   1
48)   X14 + X24 + X34 + X44 + X54                   <=   1
49)   X15 + X25 + X35 + X45 + X55                   <=   1
50)   X16 + X26 + X36 + X46 + X56                   <=   1
51)   X17 + X27 + X37 + X47 + X57                   <=   1
52)   X18 + X28 + X38 + X48 + X58                   <=   1
53)   X19 + X29 + X39 + X49 + X59                   <=   1
54)   X110 + X210 + X310 + X410 + X510              <=   1
55)   X111 + X211 + X311 + X411 + X511              <=   1
56)   X112 + X212 + X312 + X412 + X512              <=   1
57)   X113 + X213 + X313 + X413 + X513              <=   1
58)   X114 + X214 + X314 + X414 + X514              <=   1
59)   X115 + X215 + X315 + X415 + X515              <=   1
60)   X116 + X216 + X316 + X416 + X516              <=   1
61)   X117 + X217 + X317 + X417 + X517              <=   1
```

```
OBJECTIVE FUNCTION VALUE =   15.000000

VARIABLE        VALUE          REDUCED COST
    X13        1.000000          .000000
    X21        1.000000          .000000
    X26        1.000000          .000000
    X27        1.000000          .000000
   X215        1.000000          .000000
   X310        1.000000          .000000
   X316        1.000000          .000000
    X45        1.000000          .000000
   X413        1.000000          .000000
   X417        1.000000          .000000
    X52        1.000000          .000000
    X58        1.000000          .000000
    X59        1.000000          .000000
   X511        1.000000          .000000
   X512        1.000000          .000000

All other variables = 0        NO. ITERATIONS=      189
                               BRANCHES=     12 DETERM.=  1
                               BOUND ON OPTIMUM:   15
```

B.3 LINDO Solution to Range Area Allocation Example Problem -

```
MAX      X11 + X12 + X13 + X14 + X15 + X16 + X17 + X18 + X19 +
         X110 + X111 + X112 + X113 + X114 + X115 + X116 + X117 +
         X21 + X22 + X23 + X24 + X25 + X26 + X27 + X28 + X29 +
         X210 + X211 + X212 + X213 + X214 + X215 + X216 + X217 +
         X31 + X32 + X33 + X34 + X35 + X36 + X37 + X38 + X39 +
         X310 + X311 + X312 + X313 + X314 + X315 + X316 + X317 +
         X41 + X42 + X43 + X44 + X45 + X46 + X47 + X48 + X49 +
         X410 + X411 + X412 + X413 + X414 + X415 + X416 + X417 +
         X51 + X52 + X53 + X54 + X55 + X56 + X57 + X58 + X59 +
         X510 + X511 + X512 + X513 + X514 + X515 + X516 + X517 +
         X61 + X62 + X63 + X64 + X65 + X66 + X67 + X68 + X69 +
         X610 + X611 + X612 + X613 + X614 + X615 + X616 + X617 +
         X71 + X72 + X73 + X74 + X75 + X76 + X77 + X78 + X79 +
         X710 + X711 + X712 + X713 + X714 + X715 + X716 + X717

SUBJECT TO
    2)   X11 + X18 + X110 <=   1
    3)   X11 + X18 + X116 <=   1
    4)   X12 + X113 + X115 <=   1
    5)   X13 + X14 + X16 + X111 <=   1
    6)   X13 + X14 + X15 + X111 + X117 <=   1
    7)   X13 + X16 + X111 <=   1
    8)   X13 + X17 + X111 + X112 + X117 <=   1
    9)   3X11+6X12+4X18+6X19+5X110+3X113+3X114+3X115+2X116 <=   6
   10)   X21 + X28 + X210 <=   1
   11)   X21 + X28 + X216 <=   1
   12)   X22 + X213 + X215 <=   1
   13)   X23 + X24 + X26 + X211 <=   1
   14)   X23 + X24 + X25 + X211 + X217 <=   1
   15)   X23 + X26 + X211 <=   1
   16)   X23 + X27 + X211 + X212 + X217 <=   1
   17)   3X21+6X22+4X28+6X29+5X210+3X213+3X214+3X215+2X216 <=   6
   18)   X31 + X38 + X310 <=   1
   19)   X31 + X38 + X316 <=   1
   20)   X32 + X313 + X315 <=   1
   21)   X33 + X34 + X36 + X311 <=   1
   22)   X33 + X34 + X35 + X311 + X317 <=   1
   23)   X33 + X36 + X311 <=   1
   24)   X33 + X37 + X311 + X312 + X317 <=   1
   25)   3X31+6X32+4X38+6X39+5X310+3X313+3X314+3X315+2X316 <=   6
   26)   X41 + X48 + X410 <=   1
   27)   X41 + X48 + X416 <=   1
   28)   X42 + X413 + X415 <=   1
   29)   X43 + X44 + X46 + X411 <=   1
   30)   X43 + X44 + X45 + X411 + X417 <=   1
   31)   X43 + X46 + X411 <=   1
   32)   X43 + X47 + X411 + X412 + X417 <=   1
   33)   3X41+6X42+4X48+6X49+5X410+3X413+3X414+3X415+2X416 <=   6
   34)   X51 + X58 + X510 <=   1
   35)   X51 + X58 + X516 <=   1
   36)   X52 + X513 + X515 <=   1
   37)   X53 + X54 + X56 + X511 <=   1
   38)   X53 + X54 + X55 + X511 + X517 <=   1
   39)   X53 + X56 + X511 <=   1
   40)   X53 + X57 + X511 + X512 + X517 <=   1
   41)   3X51+6X52+4X58+6X59+5X510+3X513+3X514+3X515+2X516 <=   6
   42)   X61 + X68 + X610 <=   1
   43)   X61 + X68 + X616 <=   1
```

```
44)   X62 + X613 + X615 <=   1
45)   X63 + X64 + X66 + X611 <=   1
46)   X63 + X64 + X65 + X611 + X617 <=   1
47)   X63 + X66 + X611 <=   1
48)   X63 + X67 + X611 + X612 + X617 <=   1
49)   3X61+6X62+4X68+6X69+5X610+3X613+3X614+3X615+2X616 <=   6
50)   X71 + X78 + X710 <=   1
51)   X71 + X78 + X716 <=   1
52)   X72 + X713 + X715 <=   1
53)   X73 + X74 + X76 + X711 <=   1
54)   X73 + X74 + X75 + X711 + X717 <=   1
55)   X73 + X76 + X711 <=   1
56)   X73 + X77 + X711 + X712 + X717 <=   1
57)   3X71+6X72+4X78+6X79+5X710+3X713+3X714+3X715+2X716 <=   6
58)   X11 + X21 + X31 + X41 + X51 + X61 + X71 <=   1
59)   X12 + X22 + X32 + X42 + X52 + X62 + X72 <=   1
60)   X13 + X23 + X33 + X43 + X53 + X63 + X73 <=   1
61)   X14 + X24 + X34 + X44 + X54 + X64 + X74 <=   1
62)   X15 + X25 + X35 + X45 + X55 + X65 + X75 <=   1
63)   X16 + X26 + X36 + X46 + X56 + X66 + X76 <=   1
64)   X17 + X27 + X37 + X47 + X57 + X67 + X77 <=   1
65)   X18 + X28 + X38 + X48 + X58 + X68 + X78 <=   1
66)   X19 + X29 + X39 + X49 + X59 + X69 + X79 <=   1
67)   X110 + X210 + X310 + X410 + X510 + X610 + X710 <=   1
68)   X111 + X211 + X311 + X411 + X511 + X611 + X711 <=   1
69)   X112 + X212 + X312 + X412 + X512 + X612 + X712 <=   1
70)   X113 + X213 + X313 + X413 + X513 + X613 + X713 <=   1
71)   X114 + X214 + X314 + X414 + X514 + X614 + X714 <=   1
72)   X115 + X215 + X315 + X415 + X515 + X615 + X715 <=   1
73)   X116 + X216 + X316 + X416 + X516 + X616 + X716 <=   1
74)   X117 + X217 + X317 + X417 + X517 + X617 + X717 <=   1
```

OBJECTIVE FUNCTION VALUE =   17.000000

VARIABLE	VALUE	REDUCED COST
X16	1.000000	-1.000000
X18	1.000000	-1.000000
X114	1.000000	-1.000000
X25	1.000000	-1.000000
X29	1.000000	-1.000000
X212	1.000000	-1.000000
X37	1.000000	-1.000000
X316	1.000000	-1.000000
X43	1.000000	-1.000000
X415	1.000000	-1.000000
X54	1.000000	-1.000000
X510	1.000000	-1.000000
X62	1.000000	-1.000000
X611	1.000000	-1.000000
X71	1.000000	-1.000000
X713	1.000000	-1.000000
X717	1.000000	-1.000000

All other variables = 0

NO. ITERATIONS=   34
BRANCHES=   0 DETERM.=   1
BOUND ON OPTIMUM: 17

Appendix C: General Algebraic Modeling System (GAMS) Code For Resource Allocation Formulations

```
SETS
 G       general resource categories  /0*66/
 GA(G)   general aircraft categories  /0*14/
 GR(G)   general radar categories  /20*34/
 GRA(G)  general range area categories  /40*66/
 G151(G) general W151 range area categories  /42*49/
 S       specified resource categories  /0*152/
 SA(S)   specified aircraft categories  /0*55/
 SA1(S)  specified aircraft categories  /1*55/
 SR(S)   specified radar categories  /0,60*94/
 SR1(S)  specified radar categories  /60*94/
 SRA(S)  specified range area categories /0,100*136,140*152/
 SRA1(S) specified range area categories /100*136, 140*152/
 S151(S) specified 151 range area categories  /0,104*122/
 TA      aircraft time periods  /1*2/
 TR      radar time periods  /1*5/
 TR1(TR) radar time period one  /1/
 TR2(TR) radar time periods minus one period  /2*5/
 TRA     range area time periods  /1*7/
 STR(S)  specified categories of tracking radars  /60*69/
 GTR(G)  general categories of tracking radars  /20*23/
 NGTR(G) general categories of non-tracking radars  /24*34/
 J       mission number  /1*66/;

$include "datafile.dat"

PARAMETER TAV(G) # of resources available in category g
/0 100,1 1,  2 1,  3 1,  4 1,  5 20,  6 1,  7 15,
  8 3,  9 5, 10 2, 11 1, 12  2, 13 4, 14  2,
 20 4, 21 1, 22 2, 23 1, 24  2, 25 1, 26  2, 27 3,
 28 1, 29 1, 30 3, 31  1, 32 2, 33  2, 34  2/;

VARIABLES
  XA(TA,J)    indicates if test j receives all aircraft
              in period t
  XR(TR,J)    indicates if test j receives all radars
              in period t
  XRA(TRA,J)  indicates if test j receives all ranges
              in period t
  ZA          aircraft objective function value
  ZR          radar objective function value
  ZRA         range area objective function value;

BINARY VARIABLE
  XA, XR, XRA;
```

```
EQUATIONS
  ACFT            obj function for allocating aircraft only
  A1(SA1,TA)      specific aircraft constraints
  A2(GA,TA)       general aircraft constraints
  A3(J)           aircraft time period constraints
  RADAR           obj function for allocating radars only
  R1(STR,TR1)     specific tracking radar constraints
  R2(SR1,TR2)     specific radar constraints
  R3(GTR,TR1)     general tracking radar constraints
  R4(TR1)         general non-tracking radar constraints
  R5(GR,TR2)      general radar constraints
  R6(J)           radar time period constraints
  AREA            obj function for allocating range areas only
  RA1(SRA1,TRA) specific range area constraints
  RA2(TRA)        general range area constraint for W151
  RA3(J)          range area time period constraints;

** AIRCRAFT FORMULATION
ACFT .. ZA =E= SUM(TA, SUM(J, XA(TA,J)));
A1(SA1,TA) .. SUM((GA,J),REQ(GA,SA1,J)*XA(TA,J)) =L= 1;
A2(GA,TA) .. SUM((SA,J),REQ(GA,SA,J)*XA(TA,J)) =L= TAV(GA);
A3(J) .. SUM(TA,XA(TA,J)) =L= 1;

** RADAR FORMULATION
RADAR.. ZR =E= SUM(TR, SUM(J, XR(TR,J)));
R1(STR,TR1) .. SUM((GTR,J),REQ(GTR,STR,J)*XR(TR1,J)) =L= 1;
R2(SR1,TR2).. SUM((GR,J),REQ(GR,SR1,J)*XR(TR2,J)) =L= 1;
R3(GTR,TR1).. SUM((STR,J),REQ(GTR,STR,J)*XR(TR1,J)) =L=
              TAV(GTR);
R4(TR1)..SUM(NGTR,SUM((SR,J),REQ(NGTR,SR,J)*XR(TR1,J)))=E=0;
R5(GR,TR2)..SUM((SR,J),REQ(GR,SR,J)*XR(TR2,J)) =L= TAV(GR);
R6(J) .. SUM(TR,XR(TR,J)) =L= 1;

** RANGE AREA FORMULATION
AREA .. ZRA =E= SUM(TRA, SUM(J, XRA(TRA,J)));
RA1(SRA1,TRA)..SUM((GRA,J),REQ(GRA,SRA1,J)*XRA(TRA,J)) =L=1;
RA2(TRA) .. SUM((G151,S151,J),REQ(G151,S151,J)*XRA(TRA,J))
           =L= 19;
RA3(J) .. SUM(TRA,XRA(TRA,J)) =L= 1;

MODEL AIRCRAFT/ACFT,A1,A2,A3/;
OPTION OPTCR= .05;
SOLVE AIRCRAFT USING MIP MAXIMIZING ZA;
DISPLAY XA.L;
MODEL RADARS/RADAR,R1,R2,R3,R4,R5,R6/;
OPTION OPTCR= .05;
SOLVE RADARS USING MIP MAXIMIZING ZR;
DISPLAY XR.L;
MODEL RANGES/AREA,RA1,RA2,RA3/;
OPTION OPTCR= .05;
SOLVE RANGES USING MIP MAXIMIZING ZRA;
DISPLAY XRA.L;
```

Appendix D: Test Mission Resource Requirements (Input Data for 03-21 Feb 1992)

```
Feb 03 1992 -
*5278
        1
0.0     1

*5399
+       2
7.0     4
46.115  1
46.116  1
47.117  1
47.118  1

*5406
+       3
42.0    1

*5407
+       4
42.0    1

*5408
+       5
42.0    1

*5411
+       6
42.0    1

*5475
+       7
9.0     1
7.0     1
5.0     1
8.0     1
65.151  1

*5489
+       8
8.0     1
7.0     1
5.0     1
9.0     1
65.151  1

*5513
+       10
5.24    1
42.0    1

*5524
+       11
8.0     1
65.151  1

*5537
+       12
12.52   1

*5547
+       13
5.14    1
5.12    1
42.0    1

*5593
+       14
7.34    1
42.104  1
42.105  1
42.106  1
40.100  1
40.101  1
53.132  1
33.89   1
33.90   1
34.91   1
27.75   1
27.76   1
27.77   1
34.92   1
28.78   1
20.61   1
20.62   1
29.29   1
25.72   1

*5599

*5636
+       16
0.0     1
7.0     4
44.110  1
44.111  1
44.112  1
45.113  1
45.114  1
48.119  1
48.120  1
48.121  1
48.122  1
50.124  1
50.125  1
22.66   1
22.67   1

*5637
+       17
0.0     1
44.110  1
44.111  1
44.112  1
45.113  1
45.114  1
48.119  1
48.120  1
49.121  1
49.122  1
22.66   1

*5643
+       18
7.0     2
5.0     1
9.0     1
50.123  1

*5648
+       19
0.0     1
50.123  1

*5653
+       20
0.0     1
44.110  1

*5724
+       21
0.0     1
42.0    1

*5727
+       22
1.1     1
42.105  1
42.106  1
43.108  1
43.109  1
46.115  1
47.117  1
20.62   1
20.63   1

*5731
+       23
42.105  1
42.106  1
43.108  1
43.109  1
46.115  1
47.117  1
20.61   1
20.63   1

*5742
+       24
5.16    1
42.104  1
40.100  1
33.89   1
27.75   1
28.78   1
20.61   1

*5753
+       26
58.140  1

*5765
+       27
7.40    1
42.104  1
40.100  1
33.89   1
27.75   1
27.77   1
28.78   1
20.62   1
30.84   1
21.65   1

*5785
+       28
7.32    1
7.27    1
7.35    1
7.0     1
43.107  1
43.108  1
43.109  1

*5790
+       29
7.30    1
42.105  1
42.106  1

*5794
+       30
7.0     1
42.0    1

*5798
+       31
7.0     1
42.0    1
```

Feb 03 1992 continued -

```
*5810
+         33
5.0       1
65.151    1

*5817
+         34
5.0       1
65.151    1

*5827
+         35
5.0       1

*5844
+         36
0.0       1

*5846
+         37
0.0       1

*5855
+         38
5.15      1
5.6       1
5.19      1
44.110    1
44.111    1
44.112    1
45.113    1
45.114    1

*5856
+         39
5.20      1
43.107    1
43.108    1
43.109    1

*5866
+         40
7.39      1
60.144    1
62.146    1
20.61     1
*5870
+         41
0.0       1

*5872
+         42
0.0       1
40.101    1
63.148    1
66.152    1
21.65     1

*5874
+         43
0.0       1

*5875
+         44
0.0       1

*5876
+         45
7.0       1

*5879
+         46
7.40      1
5.0       1
13.0      1
42.104    1
42.105    1
42.106    1

*5880
+         47
0.0       1

*5884
+         48
0.0       1
58.142    1
59.143    1

*5885
+         49
0.0       1
58.142    1
59.143    1

*5886
+         50
0.0       1
*5890

*5896
+         52
7.0       1
42.0      1

*5900
+         53
5.0       1

*5917
+         54
7.37      1
44.110    1
44.111    1
44.112    1
45.113    1
45.114    1
22.66     1
22.67     1

*5919
+         55
2.2       1
58.140    1
58.141    1
58.142    1
60.144    1
62.146    1
20.60     1

*5926
+         56
8.0       1
5.0       1
13.0      1
42.104    1
42.105    1
42.106    1
46.115    1
46.116    1

*5933
+         57
0.0       1

*5935
+         58
0.0       1

*6243
+         59
7.40      1
40.101    1
63.148    1
66.152    1
21.65     1

*6271
+         60
5.12      1
43.107    1
43.108    1

*6407
+         61
0.0       1

*9001
+         62
7.0       1
43.107    1
43.108    1

*9002
+         63
5.0       1
45.113    1
45.114    1

*9101
+         64
0.0       1

*9102
+         65
0.0       1

*9103
+         66
0.0       1;
```

Feb 04 1992 -

*5279
1
0.0 1

*5400
+ 2
7.0 4
42.0 1

*5412
+ 3
42.0 1

*5413
+ 4
42.0 1

*5414
+ 5
42.0 1

*5415
+ 6
42.0 1

*5476
+ 7
8.43 1
9.0 1
65.151 1

*5490
+ 8
5.12 1
65.151 1

*5501
+ 9
7.0 1
5.0 1
9.0 1
42.0 4

*5514
+ 10
7.37 1
2.2 1
40.100 1
40.101 1
42.104 1
42.105 1
42.106 1
43.107 1
43.108 1
43.109 1

*5526
+ 11
8.0 1
65.151 1

*5538
+ 12
12.52 1

*5548
+ 13
42.0 1

*5588
+ 14
7.35 1
7.34 1
5.20 1
5.16 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
50.125 1
50.124 1
20.60 1
21.65 1
22.66 1
22.67 1

*5600
+ 15
0.0 1
51.128 1
51.129 1
51.130 1

*5639
+ 16
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1

*5640
+ 17
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
22.66 1

*5641
+ 18
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
50.124 1
50.125 1
22.66 1
22.67 1

*5642
+ 19
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
50.124 1
50.125 1
22.66 1
22.67 1

*5644
+ 20
7.0 2
5.0 1
9.0 1
50.123 1

*5649
+ 21
0.0 1
5.0 6
9.0 4
50.123 1
50.124 1
50.125 1
50.126 1
50.127 1

*5654
+ 22
44.110 1

*5664
+ 23
7.33 1
43.107 1
43.108 1
43.109 1

*5728
+ 24
1.1 1
9.48 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
49.121 1
22.66 1
22.67 1

*5733
+ 25
5.14 1
9.47 1
42.105 1
42.106 1
43.108 1
43.109 1
46.115 1
47.117 1
20.62 1
20.63 1

*5741
+ 26
5.6 1
5.19 1
42.104 1
40.100 1
33.89 1
33.90 1
34.91 1
27.75 1
27.77 1
28.78 1
30.84 1
24.71 1
25.72 1

Feb 04 1992 continued -

```
*5766
+       27
7.39    1
42.104  1
40.100  1
33.89   1
27.75   1
27.77   1
20.62   1
30.84   1
21.65   1

*5787
+       28
7.0     1
42.0    1

*5791
+       29
7.0     1
7.35    1
7.34    1
42.0    1

*5795
+       30
5.24    1

*5799
+       31
7.33    1

*5805
+       32
5.0     1
65.151  1

*5812
+       33
5.0     1
65.151  1

*5820
+       34
5.0     1
65.151

*5830
+       35

*5859
+       36
5.7     1
5.6     1
5.20    1
5.16    1

*5877
+       37
0.0

*5887
+       38
0.0     1

*5891
+       39
5.0     1
5.23    1
42.104  1
42.105  1
42.106  1

*5897
+       40
7.0     1
42.0    1

*5901
+       41
7.0     1
42.0    1

*5911
+       42
9.0     1
13.0    1
42.104  1
42.105  1
42.106  1
46.115  1
46.116  1
40.100  1
20.61   1
20.62   1

*5918
+       43
5.15    1

*5927
+       44
5.12    1
3.3     1
13.0    1
42.104  1
42.105  1
42.106  1
20.61   1

*5937
+       45
0.0     1

*5940
+       46
0.0     1

*5941
+       47
0.0     1

*5942
+       48
0.0     1

*5945
+       49
58.142  1
59.143  1

*5946
+       50
58.142  1
59.143  1

*5948
+       51
0.0     1

*5979
+       52
7.32    1
2.2     1
58.140  1
58.141  1
58.142  1
60.144  1
62.146  1

*5987
+       53
7.40    1
5.12    1
13.0    1
42.104  1
42.105  1
42.106  1
43.107  1
43.108  1
43.109  1
44.110  1
44.111  1
44.112  1
45.113  1
45.114  1
46.115  1
46.116  1
47.117  1
47.118  1
48.119  1
48.120  1
49.121  1
49.122  1
20.60   1
20.61   1
20.62   1
23.69   1
22.66   1
22.67   1

*5990
+       54
7.38    1
7.40    1
1.1     1
42.104  1
42.105  1
42.106  1
43.107  1
40.100  1
40.101  1
53.132  1
33.89   1
33.90   1
27.75   1
27.77   1
34.93   1
20.61   1

*5993
+       55
7.37    1
44.110  1
44.111  1
44.112  1
45.113  1
45.114  1
22.66   1
22.67   1

*5994
+       56
5.0     1
42.104  1
42.105  1
42.106  1
40.100  1
53.132  1
33.89   1
34.91   1
27.75   1
27.77   1
34.92   1
28.78   1
20.62   1
29.79   1
30.84   1
25.72   1

*6000
+       57
7.40    1
9.48    1
13.0    1
42.104  1
42.105  1
42.106  1

*6001
+       58
7.0     1
7.39    1
60.144  1
20.60   1
```

Feb 04 1992 continued -

*6006
+ 59
7.32 1
5.7 1
13.0 1
42.104 1
42.105 1
42.106 1
43.107 1
43.108 1
43.109 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
46.115 1
46.116 1
47.117 1
47.118 1
48.119 1
48.120 1
49.121 1
49.122 1
20.61 1
20.62 1
23.69 1
22.67 1

*6008
+ 60
7.30 1
7.38 1
4.4 1
13.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
20.61 1
22.66 1
22.67 1

*6045
+ 61
5.24 1
44.110 1
44.111 1

*6129
+ 62
2.2 1
42.104 1
42.105 1

*6136
+ 63
9.47 1
60.144 1
20.62 1
21.65 1

*6138
+ 64
0.0 1
42.0 1

*6156
+ 65
12.52 1

*6400
+ 66
7.0 6
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1

*9001
+ 67
0.0 1

*9201
+ 68
0.0 1

*9202
+ 69
0.0 1

*9203
+ 70
0.0 1;

Feb 05 1992 -

*5281
1
0.0 1

*5402
+ 2
7.0 4
42.0 3

*5417
+ 3
42.0 3

*5419
+ 4
42.0 3
*5421
+ 5

*5424
+ 6
42.0 3

*5477
+ 7
8.0 1
7.0 1
5.0 1
9.0 1
65.151 1

*5491
+ 8
8.0 1
7.0 1
5.0 1
9.0 1

*5502
+ 9
5.12 1
45.113 1
45.114 1

*5515
+ 10
9.48 1
46.115 1

*5527
+ 11
8.0 1
65.151 1
*5539
+ 12
2.2 1

*5549
+ 13
42.0 1
*5596
+ 14
34.93 1
7.40 1
42.104 1
42.105 1
42.106 1
40.100 1
40.101 1
33.89 1
33.90 1
34.91 1
27.75 1
27.76 1
27.77 1
28.78 1
20.62 1
29.79 1
30.81 1
30.84 1
25.72 1

*5601
+ 15
0.0 1
51.128 1
51.129 1
51.130 1
*5645
+ 16
50.123 1
7.0 2
5.0 1

Feb 05 1992 continued -

*5650
+ 17
0.0 1
5.0 6
9.0 4
50.123 1
50.124 1
50.125 1
50.126 1
50.127 1

*5655
+ 18
0.0 1
44.110 1

*5658
+ 19
7.0 4
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
50.124 1
50.125 1
22.66 1
22.67 1

*5659
+ 20
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
22.66 1

*5696
+ 21
5.20 1
44.110 1
44.111 1
44.112 1
48.119 1
48.120 1
22.67 1

*5788
+ 22
7.30 1
7.26 1
7.33 1
7.34 1
42.104 1
42.105 1

*5792
+ 23
0.0 1

*5796
+ 24
7.0 1
42.0 1

*5800
+ 25
7.0 1
42.0 1

*5806
+ 26
5.7 1
5.19 1
5.16 1
5.24 1
65.151 1

*5814
+ 27
2.2 1
65.151 1

*5821
+ 28
5.0 1
65.151 1

*5832
+ 29
5.0 1
65.151 1

*5857
+ 30
7.30 1
5.14 1
42.105 1
42.106 1
43.108 1
43.109 1
46.115 1
47.117 1
20.61 1
20.63 1

*5861
+ 31
5.7 1
5.15 1
5.19 1
5.16 1
5.24 1

*5864
+ 32
42.105 1
42.106 1
43.108 1
43.109 1
46.115 1
47.117 1
20.60 1
20.63 1

*5871
+ 33
5.0 1
42.0 1

*5878
+ 34
0.0 1

*5882
+ 35
0.0 1

*5888
+ 36
0.0 1

*5898
+ 37
7.0 1
42.0 1

*5902
+ 38
5.0 1
65.151 1

*5944
+ 39
7.40 1
44.110 1
44.111 1
44.112 1
22.66 1

*5950
+ 40
0.0 1

*5952
+ 41
0.0 1

*5953
+ 42
58.142 1
59.143 1

*5955
+ 43
0.0 1

*5958
+ 44
0.0 1

*5959
+ 45
0.0 1

*5961
+ 46
0.0 1

*5963
+ 47
0.0 1

*5982
+ 48
2.2 1
5.12 1
58.140 1
58.141 1
58.142 1
60.144 1
62.146 1
20.60 1
21.65 1

*6034
+ 49
10.50 1

*6074
+ 50
5.8 1
58.140 1
60.144 1

*6081
+ 51
7.40 1
42.104 1
40.100 1
33.89 1
27.75 1
27.77 1
28.78 1
20.62 1
30.84 1
21.65 1

*6086
+ 52
7.39 1
9.0 1
60.144 1
62.146 1
20.61 1

Feb 05 1992 continued -

*6087
+ 53
7.32 1
7.39 1
40.101 1
63.148 1
66.152 1
21.65 1

*6088
+ 54
7.39 1
9.0 1
13.0 1
42.104 1
42.105 1
42.106 1

*6089
+ 55
5.8 1
58.140 1
60.144 1

*6091
+ 56
0.0 1
5.19 1
42.104 1
42.105 1
42.106 1
43.107 1
43.108 1
43.109 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
20.63 1
21.65 1
22.66 1
22.67 1

*6092
+ 57
9.48 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
48.119 1
48.120 1
49.121 1
49.122 1
22.66 1
22.67 1

*6093
+ 58
9.47 1
60.144 1
20.62 1
21.65 1

*6097
+ 59
2.2 1
5.12 1
58.140 1
58.141 1
58.142 1
60.144 1
62.146 1
20.60 1
21.65 1

*6102
+ 60
7.37 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
22.66 1
22.67 1

*6131
+ 61
5.12 1
9.47 1
42.105 1
42.106 1
43.108 1
43.109 1
46.115 1
47.117 1

*6139
+ 62
9.0 1

*6154
+ 63
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1
22.66 1
22.67 1

*6155
+ 64
12.0 1

*6401
+ 65
0.0 1

*6445
+ 66
7.32 1

*6653
+ 67
7.0 3
48.119 1
48.120 1
49.121 1
49.122 1

*6656
+ 68
7.0 3
42.106 1
43.109 1

*6683
+ 69
42.104 1

*9001
+ 70
0.0 1
44.110 1
44.111 1
44.112 1
45.113 1
45.114 1

*9301
+ 71
0.0 1

*9302
+ 72
0.0 1;

Feb 06 1992 -

*5282
1
0.0 1

*5404
+ 2
7.0 4
42.0 1

*5426
+ 3
42.0 1

*5428
+ 4
42.0 1

*5431
+ 5
42.0 1

Feb 06 1992 continued -

```
*5433
+         6
42.0      1

*5434
+         7
42.0      1

*5478
+         8
5.12      1
9.0       1
65.151    1

*5492
+         9
8.0       1
7.0       1
5.0       1
9.0       1
65.151    1

*5503
+         10
1.1       1
9.48      1
42.106    1
43.109    1

*5516
+         11
7.30      1
7.38      1
43.107    1
43.108    1

*5528
+         12
8.0       1
65.151    1

*5540
+         13
12.52     1

*5550
+         14
0.0       1
46.116    1
47.118    1

*5589
+         15
7.33      1
7.35      1
5.19      1
5.20      1
44.110    1
44.111    1
44.112    1
45.113    1
45.114    1
48.119    1
48.120    1
49.121    1
49.122    1
50.124    1
50.125    1
20.60     1
21.65     1
22.66     1
22.67     1

*5602
+         16
0.0       1
51.128    1
51.129    1
51.130    1

*5646
+         17
7.0       2
5.0       1
9.0       1
50.123    1

*5651
+         18
0.0       1
50.123    1
50.124    1
50.125    1
50.126    1
50.127    1

*5656
+         19
0.0       1
44.110    1

*5665
+         20
7.33      1
43.107    1
43.108    1
43.109    1

*5757
+         21
7.0       4
44.110    1
44.111    1
44.112    1
45.113    1
45.114    1
48.119    1
48.120    1
49.121    1
49.122    1
50.124    1
50.125    1
22.66     1

*5758
+         22
7.0       4
44.110    1
44.111    1
44.112    1
45.113    1
45.114    1
48.119    1
48.120    1
49.121    1
49.122    1
50.124    1
50.125    1
22.66     1
22.67     1

*5761
+         23
45.113    1
45.114    1
48.120    1
49.121    1
49.122    1
22.66     1

*5762
+         24
45.113    1
45.114    1
49.121    1
49.122    1
22.67     1

*5789
+         25
7.33      1
7.35      1
46.115    1
46.116    1

*5793
+         26
42.105    1
42.106    1

*5797
+         27
7.0       1
42.0      1

*5803
+         28
7.0       1
42.0      1

*5807
+         29
5.0       1
65.151    1

*5815
+         30
5.0       1
65.151    1

*5823
+         31
5.0       1
65.151    1

*5834
+         32
5.0       1
65.151    1

*5862
+         33
5.7       1
5.15      1
5.16      1

*5873
+         34
5.15      1
5.24      1

*5881
+         35
0.0       1

*5883
+         36
0.0       1

*5889
+         37
0.0       1

*5894
+         38
5.0       1
5.23      1
42.104    1
42.105    1
42.106    1

*5899
+         39
7.0       1
42.0      1

*5903
+         40
5.0       1
65.151    1

*5965
+         41
0.0       1
58.142    1
59.143    1

*5966
+         42
0.0       1
```

Feb 06 1992 continued -

```
*5967
+       43
0.0     1

*5971
+       44
0.0     1

*5980
+       45
0.0     1

*5983
+       46
58.140  1
58.141  1
58.142  1
60.144  1
62.146  1
20.60   1
21.65   1

*5991
+       47
7.40    1
13.0    1
42.104  1
42.105  1
42.106  1
40.100  1
40.101  1
53.132  1
33.89   1
33.90   1
27.75   1
27.77   1
34.93   1
20.62   1
20.63   1

*6046
+       48
5.24    1
44.110  1
44.111  1

*6064
+       49
0.0     1

*6082
+       50
7.39    1
42.104  1
40.100  1
33.89   1
27.75   1
27.77   1
20.62   1
30.84   1
21.65   1

*6094
+       51
9.47    1
60.144  1
20.62   1
21.65   1

*6101
+       52
7.40    1
5.12    1
43.107  1
43.108  1

*6117
+       53
7.40    1
5.12    1
13.0    1
42.104  1
42.105  1
42.106  1
43.107  1
43.108  1
43.109  1
44.110  1
20.60   1
20.61   1
20.63   1
23.69   1
22.66   1
22.67   1

*6121
+       54
11.0    1
42.104  1
43.107  1
40.100  1
40.101  1
53.132  1
33.90   1
27.77   1
20.63

*6122
+       55
9.0     1
13.0    1
42.104  1
42.105  1
42.106  1
46.115  1
46.116  1
40.100  1
20.61   1
20.62   1

*6128
+       56
7.40    1
42.104  1
42.105  1
42.106  1
43.107  1
40.100  1
40.101  1
53.132  1
33.89   1
33.90   1
27.75   1
27.77   1
34.93   1
20.60   1
20.61   1
20.63   1

*6140
+       57
1.1     1
9.48    1
43.108  1
43.109  1

*6165
+       58
5.12    1
3.3     1
13.0    1
42.104  1
42.105  1
42.106  1
46.115  1
20.61   1

*6166
+       59
7.40    1
5.0     1
13.0    1
42.104  1
42.105  1
42.106  1

*6168
+       60
7.0     1
7.39    1
60.144  1

*6184
+       61
8.43    1
5.10    1
13.0    1
42.104  1
42.105  1
42.106  1

*6189
+       62
1.1     1
13.0    1
42.104  1
42.105  1
42.106  1

*6192
+       63
42.105  1
42.106  1
43.108  1
43.109  1
46.115  1
47.117  1
20.62   1
22.67   1

*6200
+       64
42.105  1
42.106  1
43.108  1
43.109  1
46.115  1
47.117  1
22.66   1
22.67   1

*6202
+       65
7.38    1
13.0    1
5.20    1
42.104  1
42.105  1
42.106  1
43.107  1
43.108  1
43 109  1
27.76   1
20.60   1
20.61   1
20.63   1

*6210
+       66
5.7     1
5.15    1
13.0    1
42.0    3
20.61   1
20.62   1
20.63   1
23.69   1
22.66   1
22.67   1
```

Feb 06 1992 continued -

*6212		*6402		*6458		*9001		*9403	
+	67	+	68	+	69	+	71	+	73
5.7	1	7.0	6	11.0	1	5.19	1	0.0	1
5.15	1	44.110	1			42.104	1		
13.0	1	44.111	1	*6733		42.105	1	*9404	
42.0	3	44.112	1	+	70			+	74
20.61	1	45.113	1	0.0	1	*9402		0.0	1;
20.62	1	45.114	1			+	72		
23.69	1	48.119	1			0.0	1		
22.67	1	48.120	1			50.126	1		
		49.121	1			50.127	1		
		49.122	1						

Feb 07 1992 -

*5022		*5504		*5647		*5763		*5951	
	1	+	8	+	14	+	18	+	21
0.0	1	7.0	1	7.0	2	44.110	1	7.0	1
		5.0	1	5.0	1	44.111	1	42.0	1
*5283		9.0	1	9.0	1	44.112	1		
+	2	42.0	1	50.123	1	45.113	1	*5954	
0.0	1					45.114	1	+	22
		*5517		*5652		22.67	1	7.0	1
*5405		+	9	+	15			42.0	1
+	3	42.0	1	0.0	1	*5947			
7.0	4			50.123	1	+	19	*5957	
42.0	1	*5529		50.124	1	2.2	1	+	23
		+	10	50.125	1	7.27	1	7.0	1
*5435		8.0	1	50.126	1	7.28	1	42.0	1
+	4	65.151	1	50.127	1	7.26	1		
42.0	1					7.33	1	*5964	
		*5541		*5657		7.35	1	+	24
*5436		+	11	+	16	7.34	1	5.0	1
+	5	12.0	1	0.0	1	5.22	1	65.151	1
42.0	1			44.110	1	5.19	1		
		*5551		*5760		5.20	1	*5968	
*5479		+	12	+	17	5.16	1	+	25
+	6	42.0	1	7.0	4	5.24	1	5.0	1
8.0	1			44.110	1	42.104	1	65.151	1
7.0	1	*5603		44.111	1	42.105	1		
5.0	1	+	13	44.112	1	42.106	1	*5969	
9.0	1	0.0	1	45.113	1	43.107	1	+	26
65.151	1	51.128	1	45.114	1	43.108	1	5.0	1
		51.129	1	48.119	1	43.109	1	65.151	1
*5493		51.130	1	48.120	1				
+	7			49.121	1	*5949		*5970	
65.151	1			49.122	1	+	20	+	27
		22.66	1	50.124	1	7.0	1	5.0	1
		22.67	1	50.125	1	42.0	1	65.151	1

Feb 07 1992 continued -

```
*5972
+       28
5.0     1
65.151  1

*5973
+       29
0.0     1

*5974
+       30
0.0     1

*5975
+       31
0.0     1

*5976
+       32
0.0     1

*5877
+       33
0.0     1

*5981
+       34
0.0     1

*5988
+       35
4.4     1
13.0    1
42.104  1
42.105  1
42.106  1
46.115  1
20.63   1
23.69   1

*5995
+       36
5.0     1
42.0    1

*5996
+       37
5.0     1
42.0    1

*5998
+       38
11.0    1
46.115  1
46.116  1
47.117  1
47.118  1

*6036
+       39
10.50   1

*6039
+       40
7.0     1
7.39    1
43.107  1
43.108  1

*6070
+       41
0.0     1

*6071
+       42
0.0     1

*6076
+       43
5.8     1
58.140  1
60.144  1

*6090
+       44
58.140  1
60.144  1

*6095
+       45
9.47    1
60.144  1
20.62   1
21.65   1

*6096
+       46
9.48    1
44.110  1
44.111  1
44.112  1
45.113  1
45.114  1
48.119  1
48.120  1
49.121  1
49.122  1
22.66   1
22.67   1

*6120
+       47
7.40    1
42.104  1
42.105  1
42.106  1
40.100  1
40.101  1
53.132  1
33.89   1
33.90   1
34.91   1
27.75   1
27.76   1
27.77   1
34.92   1
28.78   1
20.62   1
29.79   1
30.81   1
30.84   1
25.72   1

*6141
+     48
0.0   1
42.0  1

*6157
+       49
12.0    1

*6158
+       50

*6193
+       51
7.30    1
2.2     1
42.105  1
42.106  1
43.108  1
43.109  1
46.115  1
47.117  1
20.62   1
20.63   1

*6203
+       52
42.105  1
42.106  1
43.108  1
43.109  1
46.115  1
47.117  1
20.62   1
20.63   1

*6206
+       53
2.2     1
58.140  1
58.141  1
58.142  1
60.144  1
62.146  1
20.60   1
21.65   1
*6229
+       54
25.72   1
5.23    1
42.104  1
42.105  1
42.106  1
40.100  1
53.132  1
33.89   1
34.91   1
27.75   1
27.77   1
34.92   1
20.62   1

*6244
+       55
60.144  1
62.146  1
20.61   1

*6272
+       56
5.15    1
7.27    1
7.28    1
7.26    1
7.33    1
7.35    1
7.34    1
5.6     1
5.19    1
5.20    1
5.16    1
5.24    1

*6374
+       57
7.0     1
7.39    1
60.144  1
20.60   1

*6375
+       58
7.40    1
5.0     1
40.101  1
63.148  1
66.152  1
21.65   1
*6381
+       59
62.146  1
0.0     1
60.144  1
*6386
+       60
22.67   1
7.37    1
44.110  1
44.111  1
44.112  1
45.113  1
```

Feb 07 continued -

```
*6387
+        61
7.37     1
44.110   1
44.111   1
44.112   1
45.113   1
45.114   1
22.66    1
22.67    1

*6655
+        62
7.0      3

*6658
+        63
7.0      3

*6740
+        64
7.0      6
44.110   1
44.111   1
44.112   1
45.113   1
45.114   1
48.119   1
48.120   1
49.121   1
49.122   1

*9001
+        65
0.0      1
42.0     1

*9002
+        66
0.0      1
42.0     1

*9501
+        67
0.0      1

*9502
+        68
0.0      1

*9503
+        69
0.0      1

*9801
+        70
0.0      1;
```

The remaining input data for 10-21 Feb 1992 can be found under the "input1" directory on the disk provided at the end of the appendices.

FEB 03 RESULTS:

AIRCRAFT MODEL STATISTICS

```
BLOCKS OF EQUATIONS       4      SINGLE EQUATIONS     127
BLOCKS OF VARIABLES       2      SINGLE VARIABLES     133
NON ZERO ELEMENTS       465      DISCRETE VARIABLES   132
GENERATION TIME        =         1.060 SECONDS
EXECUTION TIME         =         1.650 SECONDS
**** SOLVER STATUS         1 NORMAL COMPLETION
**** MODEL STATUS          1 OPTIMAL
**** OBJECTIVE VALUE                 65.0000
**** LP SOLUTION                     65.0
```

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1		1.000	1.000	1.000	1.000	1.000
2	1.000					

+	13	14	15	16	17	18
1		1.000	1.000		1.000	
2	1.000			1.000		1.000

+	19	20	21	22	23	24
1	1.000	1.000	1.000	1.000	1.000	1.000

+	25	26	27	28	29	30
1	1.000	1.000		1.000	1.000	1.000
2			1.000			

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000	1.000	1.000

+	37	38	39	40	41	42
1	1.000	1.000	1.000	1.000	1.000	1.000

+	43	44	45	46	47	48
1	1.000	1.000	1.000	1.000	1.000	1.000

+	49	50	51	52	53	54
1	1.000	1.000		1.000	1.000	1.000
2			1.000			

+	55	56	57	58	60	61
1	1.000	1.000	1.000	1.000	1.000	1.000

+	62	63	64	65	66
1	1.000	1.000	1.000	1.000	1.000

RADAR MODEL STATISTICS

```
BLOCKS OF EQUATIONS      7     SINGLE EQUATIONS     182
BLOCKS OF VARIABLES      2     SINGLE VARIABLES     331
NON ZERO ELEMENTS      935     DISCRETE VARIABLES   330
GENERATION TIME     =          1.940 SECONDS
EXECUTION TIME      =          3.800 SECONDS
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                66.0000
**** LP SOLUTION                    66.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	14	15	16	17	18
1	1.000		1.000	1.000		1.000
5		1.000			1.000	

+	19	20	21	22	23	24
1	1.000	1.000	1.000	1.000		
3						1.000
4					1.000	

+	25	26	27	28	29	30
1	1.000	1.000		1.000	1.000	1.000
4			1.000			

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000	1.000	1.000

+	37	38	39	40	41	42
1	1.000	1.000	1.000	1.000	1.000	1.000

+	43	44	45	46	47	48
1	1.000	1.000	1.000	1.000	1.000	1.000

+	49	50	51	52	53	54
1	1.000	1.000	1.000	1.000	1.000	
4						1.000

+	55	56	57	58	59	60
1	1.000	1.000	1.000	1.000		1.000
5					1.000	

+	61	62	63	64	65	66
1	1.000	1.000	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

BLOCKS OF EQUATIONS	4	SINGLE EQUATIONS	354
BLOCKS OF VARIABLES	2	SINGLE VARIABLES	463
NON ZERO ELEMENTS	1940	DISCRETE VARIABLES	462
GENERATION TIME	=	3.640 SECONDS	
EXECUTION TIME	=	6.050 SECONDS	

**** SOLVER STATUS 1 NORMAL COMPLETION

**** MODEL STATUS 8 INTEGER SOLUTION

**** OBJECTIVE VALUE 65.0000

**** LP SOLUTION 66.0

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1	1.000		1.000	1.000		1.000
3		1.000				
5					1.000	

+	13	14	15	16	18	19
1	1.000		1.000		1.000	
4		1.000		1.000		
7						1.000

+	20	21	22	23	24	25
1		1.000				1.000
5				1.000		
7	1.000		1.000		1.000	

+	26	27	28	29	30	31
1					1.000	
2			1.000	1.000		
4						1.000
5	1.000	1.000				

+	32	33	34	35	36	37
2		1.000				
4	1.000					
6				1.000	1.000	1.000
7			1.000			

+	38	39	40	41	42	43
1			1.000	1.000		
6	1.000	1.000			1.000	1.000

+	44	45	46	47	48	49
1		1.000	1.000	1.000	1.000	
6	1.000					1.000

+	50	51	52	53	54	55
1	1.000					
3		1.000	1.000	1.000	1.000	1.000

+	56	57	58	59	60	61
1			1.000		1.000	1.000
3	1.000	1.000				
5				1.000		

+	62	63	64	65	66
1			1.000	1.000	1.000
4	1.000				
7		1.000			

FEB 04 RESULTS:

AIRCRAFT MODEL STATISTICS

BLOCKS OF EQUATIONS	4	SINGLE EQUATIONS	147
BLOCKS OF VARIABLES	2	SINGLE VARIABLES	141
NON ZERO ELEMENTS	549	DISCRETE VARIABLES	140
GENERATION TIME	=	1.250 SECONDS	
EXECUTION TIME	=	1.830 SECONDS	
**** SOLVER STATUS	1 NORMAL COMPLETION		
**** MODEL STATUS	8 INTEGER SOLUTION		
**** OBJECTIVE VALUE		65.0000	
**** LP SOLUTION		66.8	

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1	1.000		1.000		1.000	
2		1.000		1.000		1.000

+	13	14	15	16	17	18
1	1.000	1.000	1.000	1.000	1.000	1.000

+	19	20	22	23	24	25
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	26	27	28	29	30	31
1	1.000	1.000	1.000			1.000
2				1.000	1.000	

+	32	33	34	35	36	37
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	38	39	40	41	42	43
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	44	45	46	47	48	49
1	1.000	1.000	1.000	1.000	1.000	1.000

+	50	51	54	55	56	58
1	1.000	1.000		1.000	1.000	
2			1.000			1.000

+	59	60	61	62	63	64
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	65	67	68	69	70
1	1.000	1.000	1.000	1.000	1.000

RADAR MODEL STATISTICS

```
BLOCKS OF EQUATIONS      7      SINGLE EQUATIONS     212
BLOCKS OF VARIABLES      2      SINGLE VARIABLES     351
NON ZERO ELEMENTS     1243      DISCRETE VARIABLES   350
GENERATION TIME     =           2.360 SECONDS
EXECUTION TIME      =           4.270 SECONDS
**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        1 OPTIMAL
**** OBJECTIVE VALUE                 65.0000
**** LP SOLUTION                     65.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	15	16	17	18	19
1	1.000	1.000	1.000			
2					1.000	
3						1.000
5				1.000		

+	20	21	22	23	24	25
1	1.000	1.000	1.000	1.000		
4					1.000	1.000

+	26	28	29	30	31	32
1		1.000				
4	1.000					
5			1.000	1.000	1.000	1.000

+	33	34	35	36	37	38
1		1.000				
4			1.000	1.000	1.000	1.000
5	1.000					

+	39	40	41	42	43	44
1		1.000				
2						1.000
3			1.000	1.000	1.000	
4	1.000					

+	45	46	47	48	49	50
2			1.000	1.000	1.000	1.000
3	1.000	1.000				

+	51	52	55	56	57	58
1			1.000		1.000	1.000
2	1.000	1.000		1.000		

+	59	61	62	63	64	65
1		1.000	1.000	1.000	1.000	1.000
5	1.000					

+	66	67	68	69	70
1	1.000	1.000	1.000		
5				1.000	1.000

RANGE AREA MODEL STATISTICS

```
BLOCKS OF EQUATIONS       4      SINGLE EQUATIONS      337
BLOCKS OF VARIABLES       2      SINGLE VARIABLES      491
NON ZERO ELEMENTS      2605      DISCRETE VARIABLES    490
GENERATION TIME        =         4.680 SECONDS
EXECUTION TIME         =         7.290 SECONDS
**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        8 INTEGER SOLUTION
**** OBJECTIVE VALUE                60.0000
**** LP SOLUTION                    61.0
```

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1			1.000			1.000
2	1.000			1.000		
4					1.000	
6		1.000				

+	13	14	15	16	17	18
1			1.000	1.000		
2						1.000
3		1.000				
4	1.000				1.000	

+	19	20	21	22	23	25
1			1.000			
3					1.000	
4						1.000
6	1.000	1.000				
7				1.000		

+	26	27	28	29	30	31
1	1.000				1.000	1.000
3		1.000				
4			1.000	1.000		

+	32	33	34	35	36	37
1		1.000				1.000
3	1.000		1.000		1.000	
7				1.000		

+	38	39	40	41	42	43
1	1.000					
2			1.000	1.000		1.000
5					1.000	
7		1.000				

+	45	46	47	48	49	50
1						1.000
3	1.000	1.000	1.000	1.000	1.000	

+	51	52	58	62	63	64
1	1.000		1.000			
5					1.000	1.000
6		1.000		1.000		

+	65	66	67	68	69	70
1				1.000	1.000	1.000
5	1.000	1.000	1.000			

FEB 05 RESULTS:

AIRCRAFT MODEL STATISTICS

BLOCKS OF EQUATIONS	4	SINGLE EQUATIONS	135
BLOCKS OF VARIABLES	2	SINGLE VARIABLES	145
NON ZERO ELEMENTS	539	DISCRETE VARIABLES	144

GENERATION TIME = 1.210 SECONDS
EXECUTION TIME = 1.780 SECONDS
**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 8 INTEGER SOLUTION
**** OBJECTIVE VALUE 65.0000
**** LP SOLUTION 65.5

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1		1.000	1.000		1.000	
2	1.000			1.000		1.000

+	13	14	15	16	18	19
1	1.000		1.000		1.000	
2		1.000		1.000		1.000

+	20	21	23	24	25	26
1	1.000	1.000	1.000	1.000	1.000	
2						1.000

+	27	28	29	30	31	32
1	1.000	1.000	1.000	1.000	1.000	1.000

+	33	34	35	36	37	38
1	1.000	1.000	1.000	1.000	1.000	1.000

+	39	40	41	42	43	44
1	1.000	1.000	1.000	1.000	1.000	1.000

+	45	46	47	49	50	52
1	1.000	1.000	1.000	1.000	1.000	1.000

+	53	55	57	58	60	61
1			1.000	1.000	1.000	
2	1.000	1.000				1.000

+	62	63	64	65	66	67
1	1.000	1.000	1.000	1.000	1.000	1.000

+	68	69	70	71	72
1	1.000	1.000	1.000	1.000	1.000

RADAR MODEL STATISTICS

```
BLOCKS OF EQUATIONS       7       SINGLE EQUATIONS      204
BLOCKS OF VARIABLES       2       SINGLE VARIABLES      361
NON ZERO ELEMENTS      1104       DISCRETE VARIABLES    360
GENERATION TIME        =          2.120 SECONDS
EXECUTION TIME         =          3.870 SECONDS
**** SOLVER STATUS        1 NORMAL COMPLETION
**** MODEL STATUS         8 INTEGER SOLUTION
**** OBJECTIVE VALUE                69.0000
**** LP SOLUTION                    70.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	15	16	17	18	19
1	1.000	1.000				
5			1.000	1.000	1.000	1.000

+	20	21	22	23	24	25
1	1.000					
4		1.000	1.000	1.000	1.000	1.000

+	26	27	28	29	30	31
1	1.000					
3		1.000	1.000	1.000	1.000	1.000

+	32	33	34	35	36	37
1	1.000					
2		1.000	1.000	1.000	1.000	1.000

+	38	39	40	41	42	43
1	1.000		1.000	1.000	1.000	1.000
4		1.000				

+	44	45	46	47	48	49
1	1.000	1.000	1.000	1.000		1.000
3					1.000	

+	50	51	52	53	54	55
1	1.000		1.000			
2		1.000				
5				1.000	1.000	1.000

+	57	58	59	60	61	62
1		1.000				
2	1.000					
3				1.000		
4			1.000		1.000	1.000

+	64	65	66	67	68	69
1	1.000					
3		1.000	1.000	1.000	1.000	1.000

+	70	71	72
1	1.000		
2		1.000	1.000

RANGE AREA MODEL STATISTICS

BLOCKS OF EQUATIONS 4 SINGLE EQUATIONS 332
BLOCKS OF VARIABLES 2 SINGLE VARIABLES 505
NON ZERO ELEMENTS 2234 DISCRETE VARIABLES 504
GENERATION TIME = 3.890 SECONDS
EXECUTION TIME = 6.300 SECONDS
**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 8 INTEGER SOLUTION
**** OBJECTIVE VALUE 67.0000
**** LP SOLUTION 68.0

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	3	4	5	6	7
1	1.000	1.000	1.000			1.000
3				1.000	1.000	

+	8	9	10	12	13	14
1		1.000		1.000	1.000	
3	1.000					
5			1.000			1.000

+	15	16	17	18	19	20
1	1.000	1.000		1.000		
3					1.000	
6						1.000
7			1.000			

+	22	23	24	25	26	27
2					1.000	
3	1.000	1.000				
5			1.000	1.000		
7						1.000

+	28	29	30	31	32	33
1				1.000		1.000
4	1.000		1.000			
6		1.000			1.000	

+	34	35	36	37	38	39
1	1.000	1.000	1.000			
5				1.000	1.000	1.000

+	40	41	42	43	44	45
5	1.000	1.000				
7			1.000	1.000	1.000	1.000

+	46	47	48	49	50	51
1		1.000				1.000
2	1.000			1.000	1.000	
3			1.000			

+	52	53	54	55	56	58
2		1.000	1.000			
4						1.000
6	1.000					
7				1.000	1.000	

+	59	61	62	63	64	65
1	1.000	1.000	1.000			
2				1.000	1.000	1.000

+	66	67	68	69	70	71
2	1.000	1.000				
3			1.000			
4				1.000	1.000	1.000

+	72
6	1.000

FEB 06 RESULTS:

AIRCRAFT MODEL STATISTICS

BLOCKS OF EQUATIONS	4	SINGLE EQUATIONS	137
BLOCKS OF VARIABLES	2	SINGLE VARIABLES	149
NON ZERO ELEMENTS	561	DISCRETF VARIABLES	148

GENERATION TIME = 1.280 SECONDS
EXECUTION TIME = 1.740 SECONDS
**** SOLVER STATU 1 NORMAL COMPLETION
**** MODEL STATUS 8 INTEGER SOLUTION
**** OBJECTIVE VALUE 66.0000
**** LP SOLUTION 66.2

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1	1.000		1.000			1.000
2		1.000		1.000	1.000	

+	13	14	15	16	17	18
1	1.000	1.000		1.000	1.000	1.000
2			1.000			

+	19	20	21	22	23	24
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	26	27	28	29	30	31
1	1.000	1.000	1.000	1.000	1.000	1.000

+	32	33	34	35	36	37
1	1.000	1.000		1.000	1.000	1.000
2			1.000			

+	38	39	40	41	42	43
1	1.000	1.000	1.000	1.000	1.000	1.000

+	44	45	46	47	48	49
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	50	51	54	55	56	57
1	1.000	1.000		1.000	1.000	1.000
2			1.000			

+	58	60	61	63	64	65
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	69	70	71	72	73	74
1	1.000	1.000	1.000	1.000	1 000	1 000

RADAR MODEL STATISTICS

```
BLOCKS OF EQUATIONS       7      SINGLE EQUATIONS      180
BLOCKS OF VARIABLES       2      SINGLE VARIABLES      371
NON ZERO ELEMENTS      1242      DISCRETE VARIABLES    370
GENERATION TIME          =       2.330 SECONDS
EXECUTION TIME           =       4.190 SECONDS
**** SOLVER STATUS        1 NORMAL COMPLETION
**** MODEL STATUS         8 INTEGER SOLUTION
**** OBJECTIVE VALUE               69.0000
**** LP SOLUTION                   70.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	14	15	16	17	18
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	19	20	21	22	23	24
2			1.000			
3					1.000	1.000
4	1.000	1.000		1.000		

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000	1.000	1.000

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000	1.000	1.000

+	37	38	39	40	41	42
1	1.000	1.000	1.000	1.000		
3					1.000	1.000

+	43	44	45	46	47	48
1						1.000
2				1.000	1.000	
3	1.000	1.000	1.000			

+	49	50	51	52	53	54
4			1.000			1.000
5	1.000	1.000		1.000	1.000	

+	55	56	57	58	59	60
1	1.000		1.000		1.000	1.000
2				1.000		
3		1.000				

+	61	62	65	68	69	70
1	1.000	1.000		1.000	1.000	1.000
4			1.000			

+	71	72	73	74
4	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

BLOCKS OF EQUATIONS	4	SINGLE EQUATIONS	341
BLOCKS OF VARIABLES	2	SINGLE VARIABLES	519
NON ZERO ELEMENTS	2507	DISCRETE VARIABLES	518
GENERATION TIME	= .	4.470 SECONDS	
EXECUTION TIME	=	6.890 SECONDS	

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 8 INTEGER SOLUTION
**** OBJECTIVE VALUE 65.0000
**** LP SOLUTION 66.0

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000					
2						1.000
3			1.000	1.000		
5					1.000	
6		1.000				

+	13	14	15	16	17	18
1	1.000	1.000		1.000	1.000	
5						1.000
7			1.000			

+	19	20	21	22	23	24
2		1.000				
3			1.000			
4				1.000		
5	1.000					1.000
6					1.000	

+	25	26	27	28	29	30
1					1.000	
2		1.000	1.000	1.000		
3	1.000					
7						1.000

+	31	33	34	35	36	37
1		1.000	1.000	1.000	1.000	1.000
4	1.000					

+	38	39	40	41	42	43
5		1.000	1.000	1.000	1.000	1.000
7	1.000					

+	44	45	46	47	48	49
1			1.000			
2	1.000	1.000				
5				1.000		
6					1.000	1.000

+	50	51	52	54	57	58
1				1.000		
3			1.000			
4					1.000	1.000
6	1.000	1.000				

+	60	63	64	66	67	69
1			1.000			
2				1.000	1.000	1.000
4	1.000					
6		1.000				

+	70	71	72	73	74
1			1.000	1.000	1.000
2	1.000				
3		1.000			

FEB 07 RESULTS:

AIRCRAFT MODEL STATISTICS

```
BLOCKS OF EQUATIONS      4      SINGLE EQUATIONS     141
BLOCKS OF VARIABLES      2      SINGLE VARIABLES     141
NON ZERO ELEMENTS      507      DISCRETE VARIABLES   140
GENERATION TIME       =         1.240 SECONDS
EXECUTION TIME        =         1.750 SECONDS
**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        8 INTEGER SOLUTION
**** OBJECTIVE VALUE                 66.0000
**** LP SOLUTION                     66.75
```

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	4	5	6	7
1	1.000	1.000	1.000	1.000	1.000	1.000

+	8	9	10	11	12	13
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	14	15	16	17	18	20
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	21	22	23	24	25	26
1	1.000	1.000	1.000	1.000	1.000	1.000

+	27	28	29	30	31	32
1	1.000	1.000	1.000	1.000	1.000	1.000

+	33	34	35	36	37	38
1	1.000	1.000	1.000	1.000	1.000	1.000

+	39	40	41	42	43	44
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	45	46	47	48	49	50
1	1.000	1.000		1.000	1.000	1.000
2			1.000			

+	51	52	53	54	55	57
1		1.000	1.000	1.000	1.000	1.000
2	1.000					

+	58	59	60	61	62	63
1	1.000	1.000		1.000		1.000
2			1.000		1.000	

+	65	66	67	68	69	70
1	1.000	1.000	1.000	1.000	1.000	1.000

RADAR MODEL STATISTICS

```
BLOCKS OF EQUATIONS      7      SINGLE EQUATIONS      208
BLOCKS OF VARIABLES      2      SINGLE VARIABLES      351
NON ZERO ELEMENTS     1045      DISCRETE VARIABLES    350
GENERATION TIME       =         2.010 SECONDS
EXECUTION TIME        =         3.870 SECONDS
**** SOLVER STATUS        1 NORMAL COMPLETION
**** MODEL STATUS         1 OPTIMAL
**** OBJECTIVE VALUE                  70.0000
**** LP SOLUTION                      70.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	14	15	16	17	18
1	1.000	1.000	1.000	1.000		
2					1.000	
4						1.000

+	19	20	21	22	23	24
1	1.0[illegible]	1.000	1.000	1.000	1.000	1.000

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000	1.000	1.000

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	37	38	39	40	41	42
1	1.000	1.000	1.000	1.000		
5					1.000	1.000

+	43	44	45	46	47	48
1				1.000		1.000
3					1.000	
5	1.000	1.000	1.000			

+	49	50	51	52	53	54
1	1.000	1.000		1.000		
2						1.000
4			1.000		1.000	

+	55	56	57	58	59	60
1		1.000	1.000	1.000	1.000	
4	1.000					
5						1.000

+	61	62	63	64	65	66
1						1.000
3	1.000	1.000	1.000	1.000	1.000	

+	67	68	69	70
1	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

```
BLOCKS OF EQUATIONS      4      SINGLE EQUATIONS     344
BLOCKS OF VARIABLES      2      SINGLE VARIABLES     491
NON ZERO ELEMENTS     2024      DISCRETE VARIABLES   490
GENERATION TIME       =         3.790 SECONDS
EXECUTION TIME        =         6.360 SECONDS
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                 69.0000
**** LP SOLUTION                     69.0
```

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	
4						1.000

+	7	8	9	10	11	12
1		1 000	1.000		1.000	1.000
2	1.000					
6				1.000		

+	13	14	15	16	17	18
1	1.000		1.000	1.000		
3		1.000				
4					1.000	
5						1.000

+	19	20	21	22	23	24
1		1.000		1.000	1.000	1.000
3			1.000			
6	1.000					

+	25	26	27	29	30	31
1					1.000	1.000
3	1.000			1.000		
5		1.000				
7			1.000			

+	32	33	34	35	36	37
1	1.000	1.000	1.000		1.000	1.000
3				1.000		

+	38	39	40	41	42	43
1		1.000				1.000
2	1.000		1.000			
5				1.000	1.000	

+	44	45	46	47	48	49
1				1.000	1.000	
3	1.000					
5						1.000
6		1.000	1.000			

+	50	51	52	53	54	55
2					1.000	1.000
5	1.000	1.000		1.000		
7			1.000			

+	56	57	58	59	60	61
1	1.000					
3						1.000
4				1.000		
7		1.000	1.000		1.000	

+	62	63	64	65	66	67
1	1.000	1.000				
2			1.000			
7				1.000	1.000	1.000

+	68	69	70
1			1.000
7	1.000	1.000	

The remaining output data for 10-21 Feb 1992 can be found under the output1" directory on the disk provided at the end of the appendices.

Appendix F: GAMS Results Using Reduced Test Mission Data Sets

FEB 03 RESULTS:

AIRCRAFT MODEL STATISTICS

```
**** SOLVER STATUS        1 NORMAL COMPLETION
**** MODEL STATUS         8 INTEGER SOLUTION
**** OBJECTIVE VALUE                56.0000
**** LP SOLUTION                    57.0
```

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

```
       1          2          3          4          5          6
1  1.000                 1.000      1.000      1.000      1.000
2             1.000

+      7          8          9         10         11         12
1  1.000      1.000      1.000      1.000                 1.000
2                                              1.000

+     13         15         16         17         18         19
1  1.000      1.000      1.000      1.000      1.000      1.000

+     20         21         22         23         24         25
1  1.000      1.000      1.000      1.000      1.000
2                                                         1.000

+     26         27         28         29         30         31
1  1.000      1.000      1.000      1.000      1.000      1.000

+     32         33         34         35         36         37
1  1.000      1.000      1.000      1.000      1.000      1.000

+     38         39         40         41         42         43
1  1.000      1.000      1.000      1.000      1.000      1.000

+     44         45         46         47         48         49
1  1.000      1.000      1.000      1.000      1.000      1.000

+     50         51         52         53         54         55
1  1.000      1.000      1.000      1.000      1.000      1.000

+     56         57
1  1.000      1.000
```

RADAR MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                  57.0000
**** LP SOLUTION                      57.0
```

```
INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

    1            2            3            4            5            6
1 1.000        1.000        1.000        1.000        1.000        1.000

+   7            8            9           10           11           12
1 1.000        1.000        1.000        1.000        1.000
3                                                                1.000

+  13           14           15           16           17           18
1 1.000                                  1.000        1.000        1.000
2                           1.000
3              1.000

+  19           20           21           22           23           24
1 1.000        1.000                                  1.000        1.000
2                             1.000
4                                        1.000

+  25           26           27           28           29           30
1              1.000        1.000        1.000        1.000        1.000
2 1.000

+  31           32           33           34           35           36
1 1.000        1.000        1.000        1.000        1.000        1.000

+  37           38           39           40           41           42
1 1.000        1.000        1.000        1.000        1.000        1.000

+  43           44           45           46           47           48
1 1.000        1.000        1.000        1.000        1.000        1.000

+  49           50           51           52           53           54
1 1.000        1.000        1.000        1.000        1.000        1.000

+  55           56           57
1 1.000        1.000        1.000
```

RANGE AREA MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       8 INTEGER SOLUTION
**** OBJECTIVE VALUE                  56.0000
**** LP SOLUTION                      57.0
```

```
INDICATES IF TEST J RECEIVES ALL RANGES IN  PERIOD T

    1            3            4            5            6            7
1 1.000        1.000        1.000        1.000        1.000        1.000

+   8            9           10           11           12           13
1 1.000                     1.000        1.000        1.000        1.000
7              1.000
```

+	14	15	16	17	18	19
1			1.000		1.000	1.000
3	1.000					
4		1.000				
6				1.000		

+	20	21	22	23	24	25
1				1.000		
4		1.000	1.000			
5					1.000	1.000
6	1.000					

+	26	27	28	29	30	31
2	1.000		1.000	1.000		1.000
4					1.000	
5		1.000				

+	32	33	34	35	36	37
1	1.000					
4		1.000				
7			1.000	1.000	1.000	1.000

+	38	39	40	41	42	43
1						1.000
3		1.000	1.000			
6				1.000	1.000	
7	1.000					

+	44	45	46	47	48	49
2			1.000	1.000		
5					1.000	1.000
6	1.000	1.000				

+	50	51	52	53	54	55
1				1.000	1.000	1.000
5	1.000	1.000	1.000			

+	56	57
1	1.000	1.000

FEB 04 RESULTS:

AIRCRAFT MODEL STATISTICS

```
**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        8 INTEGER SOLUTION
**** OBJECTIVE VALUE                53.0000
**** LP SOLUTION                    55.0
```

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1	1.000	1.000			1.000	1.000
2			1.000	1.000		

+	13	14	15	16	17	19
1	1.000	1.000	1.000	1.000	1.000	1.000

+	20	21	22	23	24	25
1					1.000	1.000
2	1.000	1.000	1.000	1.000		

+	26	27	28	29	30	31
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	32	33	34	35	36	37
1	1.000	1.000	1.000	1.000	1.000	1.000

+	38	39	40	41	42	43
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	44	45	46	47	48	50
1	1.000	1.000			1.000	1.000
2			1.000	1.000		

+	51	53	54	55	56
1	1.000	1.000	1.000	1.000	1.000

RADAR MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                54.0000
**** LP SOLUTION                    54.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	14	15	16	17	18
1	1.000	1.000			1.000	1.000
3				1.000		
5			1.000			

+	19	20	21	22	23	24
1	1.000	1.000				
3						1.000
4			1.000	1.000	1.000	

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000	1.000	1.000

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000	1.000	1.000

+	37	38	39	40	41	43
1	1.000	1.000	1.000	1.000		
2					1.000	
5						1.000

+	44	45	46	48	49	50
1			1.000	1.000	1.000	1.000
2	1.000	1.000				

+	51	52	53	54	55	56
1	1.000	1.000	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                 52.0000
**** LP SOLUTION                     52.0
```

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	
6						1.000

+	7	8	9	10	11	12
1		1.000	1.000	1.000		
2					1.000	1.000
6	1.000					

+	13	14	15	16	17	18
1						1.000
2	1.000					
4			1.000			
5				1.000		
7		1.000			1.000	

+	19	20	21	22	23	24
1	1.000					
2		1.000			1.000	
3			1.000	1.000		1.000

+	25	26	27	28	29	30
1		1.000	1.000	1.000	1.000	1.000
3	1.000					

+	31	32	33	34	35	36
1						1.000
4	1.000		1.000	1.000	1.000	
6		1.000				

+	37	38	39	40	41	43
1	1.000	1.000		1.000		
2			1.000			
4					1.000	1.000

+	44	45	46	49	50	51
1					1.000	1.000
2			1.000			
5				1.000		
6	1.000					
7		1.000				

+	53	54	55	56
1				1.000
6	1.000	1 000	1.000	

FEB 05 RESULTS:

AIRCRAFT MODEL STATISTICS

```
**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        8 INTEGER SOLUTION
**** OBJECTIVE VALUE                51.0000
**** LP SOLUTION                    52.75
```

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	12	14
1	1.000			1.000	1.000	1.000
2		1.000	1.000			

+	15	16	17	18	19	20
1	1.000		1.000		1.000	1.000
2		1.000		1.000		

+	21	22	23	24	25	26
1	1.000	1.000	1.000	1.000	1.000	1.000

+	27	28	29	30	31	32
1	1.000	1.000	1.000	1.000	1.000	1.000

+	33	34	35	36	37	38
1	1.000	1.000	1.000		1.000	
2				1.000		1.000

+	39	41	42	43	44	45
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	46	47	48	49	50	51
1	1.000	1.000	1.000	1.000	1.000	1.000

+	52	53	54
1	1.000	1.000	1.000

RADAR MODEL STATISTICS

```
**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        1 OPTIMAL
**** OBJECTIVE VALUE                53.0000
**** LP SOLUTION                    53.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	14	15	16	17	18
1			1.000	1.000	1.000	1.000
3		1.000				
4	1.000					

+	19	20	21	22	23	24
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000	1.000	1.000

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000	1.000	1.000

+	37	38	39	40	41	42
1	1.000	1.000	1.000			
2					1.000	1.000
5				1.000		

+	43	44	46	47	48	49
1	1.000	1.000	1.000	1.000	1.000	1.000

+	50	51	52	53	54
1	1.000	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                51.0000
**** LP SOLUTION                    51.0
```

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	4	5	6	7
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	8	9	10	11	12	13
1	1.000	1.000	1.000		1.000	
3						1.000
6				1.000		

+	14	16	17	18	19	20
1		1.000	1.000	1.000		
7	1.000				1.000	1.000

+	21	22	23	24	25	26
1	1.000		1.000	1.000	1.000	
3		1.000				
5						1.000

+	27	28	29	30	31	32
1	1.000	1.000	1.000	1.000	1.000	1.000

+	33	34	35	36	37	38
1						1.000
3	1.000	1.000	1.000	1.000		
6					1.000	

+	39	41	42	43	44	45
1			1.000		1.000	
2						1.000
4	1.000	1.000		1.000		

+	46	47	48	49	50	51
1	1.000					
2		1.000	1.000	1.000	1.000	
6						1.000

+	52	53	54
6	1.000	1.000	1.000

FEB 06 RESULTS:

AIRCRAFT MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       8 INTEGER SOLUTION
**** OBJECTIVE VALUE                50.0000
**** LP SOLUTION                    51.0
```

INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

	1	2	3	4	5	6
1	1.000		1.000	1.000	1.000	1.000
2		1.000				

+	7	8	9	10	11	12
1	1.000	1.000			1.000	1.000
2			1.000	1.000		

+	13	14	15	16	17	18
1	1.000	1.000	1.000	1.000	1.000	1.000

+	19	20	21	22	23	24
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000	1.000	1.000

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000	1.000	1.000

+	37	38	39	41	43	45
1			1.000	1.000		1.000
2	1.000	1.000			1.000	

+	46	47	51	52	53	54
1	1.000	1.000	1.000	1.000	1.000	1.000

+	55	56
1	1.000	1.000

RADAR MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       8 INTEGER SOLUTION
**** OBJECTIVE VALUE               54.0000
**** LP SOLUTION                   55.0
```

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000	1.000	1.000

+	13	14	15	16	17	18
1	1.000	1.000	1.000	1.000	1.000	
4						1.000

+	19	20	21	22	23	24
1		1.000	1.000	1.000	1.000	1.000
3	1.000					

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000	1.000	1.000

+	31	32	33	34	35	36
1	1.000	1.000		1.000	1.000	
3			1.000			
4						1.000

+	37	38	39	41	42	43
1	1.000			1.000	1.000	1.000
2		1.000				
5			1.000			

+	44	45	46	47	48	50
1	1.000				1.000	1.000
2		1.000		1.000		
5			1.000			

+	51	52	53	54	55	56
1	1.000	1.000	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE               52.0000
**** LP SOLUTION                   52.0
```

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000				1.000
2			1.000		1.000	
7				1.000		

```
+  13         14         15         16         17         18
1 1.000      1.000      1.000
3                                                       1.000
5                                 1.000      1.000

+  19         20         21         22         23         24
1 1.000                 1.000      1.000      1.000      1.000
3            1.000

+  25         26         27         28         29         30
1                                                       1.000
6 1.000      1.000                 1.000      1.000
7                       1.000

+  31         32         33         34         35         36
1 1.000      1.000                 1.000      1.000      1.000
5                       1.000

+  37         38         39         40         41         43
1 1.000                                                 1.000
3                                  1.000      1.000
4                       1.000
6            1.000

+  45         48         49         50         51         52
4                       1.000      1.000      1.000      1.000
6 1.000      1.000

+  53         54         55         56
2 1.000      1.000      1.000      1.000
```

FEB 07 RESULTS:

AIRCRAFT MODEL STATISTICS

```
**** SOLVER STATUS        1 NORMAL COMPLETION
**** MODEL STATUS         8 INTEGER SOLUTION
**** OBJECTIVE VALUE                43.0000
**** LP SOLUTION                    44.2
```

```
INDICATES IF TEST J RECEIVES ALL AIRCRAFT IN PERIOD T

    1          2          3          4          5          6
1 1.000      1.000      1.000      1.000      1.000      1.000

+   7          8          9         10         11         12
1 1.000      1.000      1.000      1.000      1.000      1.000

+  13         14         15         16         17         18
1            1.000      1.000      1.000      1.000      1.000
2 1.000

+  19         20         21         22         23         24
1 1.000      1.000      1.000      1.000                 1.000
2                                             1.000

+  25         26         27         28         29         30
1 1.000      1.000      1.000      1.000      1.000
2                                                       1.000
```

+	31	32	34	35	36	37
1	1.000	1.000	1.000	1.000	1.000	
2						1.000

+	38	41	42	43	44	45
1		1.000	1.000	1.000	1.000	1.000
2	1.000					

+	46
1	1.000

RADAR MODEL STATISTICS

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 46.0000
**** LP SOLUTION 46.0

INDICATES IF TEST J RECEIVES ALL RADARS IN PERIOD T

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000	1.000		
2						1.000
4					1.000	

+	13	14	15	16	17	18
1	1.000	1.000	1.000	1.000	1.000	1.000

+	19	20	21	22	23	24
1	1.000	1.000	1.000	1.000	1.000	1.000

+	25	26	27	28	29	30
1	1.000	1.000	1.000	1.000		
2						1.000
3					1.000	

+	31	32	33	34	35	36
1		1.000	1.000	1.000		1.000
2					1.000	
3	1.000					

+	37	38	39	40	41	42
1	1.000	1.000	1.000	1.000	1.000	1.000

+	43	44	45	46
1	1.000	1.000	1.000	1.000

RANGE AREA MODEL STATISTICS

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE                  46.0000
**** LP SOLUTION                      46.0

INDICATES IF TEST J RECEIVES ALL RANGES IN PERIOD T

    1            2            3            4            5            6
1 1.000        1.000        1.000        1.000        1.000        1.000

+   7            8            9           10           11           12
1 1.000        1.000
2                           1.000                                  1.000
4                                                     1.000
7                                        1.000

+  13           14           15           16           17           18
1              1.000        1.000        1.000        1.000        1.000
4 1.000

+  19           20           21           22           23           24
1 1.000                     1.000        1.000        1.000        1.000
7              1.000

+  25           26           27           28           29           30
2                                                                  1.000
3                                        1.000
6 1.000        1.000                                  1.000
7                           1.000

+  31           32           33           34           35           36
1 1.000                                  1.000
2                                                                  1.000
4              1.000
6                           1.000                     1.000

+  37           38           39           40           41           42
1 1.000
3                                        1.000        1.000        1.000
6              1.000        1.000

+  43           44           45           46
3 1.000        1.000
6                           1.000        1.000
```

The remaining output data for 10-21 Feb 1992 can be found under the "output2" directory on the disk provided at the end of the appendices.

Appendix G: Comparison of Actual Versus Modeled Results Using Full Test Mission Data Sets

The following weekly listings of TW missions are presented by mission number with codes identifying only missions that were non-scheduled or canceled.

	Actual	Model
Non-Scheduled Reasons:	A = Aircraft	a = aircraft
	R = Radar	r = radar
	RA = Range Area	ra = range area
	OT = Other	
Canceled Reasons:	BU = Backup or Alternate Mission	
	CX = Canceled for other reasons	

WEEK OF 03-07 FEB 1992

	FEB 03		FEB 04		FEB 05		FEB 06		FEB 07	
01	5278		5279		5281		5282		5022	
02	5399		5400		5402	ra	5404		5283	
03	5406		5412	RA	5417		5426		5405	a
04	5407		5413		5419		5428		5435	
05	5408		5414		5421		5431		5436	
06	5411		5415	RA	5424		5433		5479	BU
07	5475	BU	5476		5477	BU	5434		5493	BU
08	5489	BU	5490		5491	BU	5478		5504	BU
09	5500		5501	BU	5502		5492	BU	5517	BU
10	5513		5514		5515		5503		5529	BU
11	5524	A	5526	BU	5527	BU,ra	5516		5541	BU
12	5537		5538		5539		5528		5551	
13	5547		5548	OT	5549	BU	5540		5603	
14	5593		5588	CX,r	5596	BU,r	5550		5647	
15	5599		5600		5601		5589	BU	5652	
16	5636		5639		5645		5602		5657	ra
17	5637	r	5640	R	5650	a	5646		5760	ra
18	5643		5641	R,RA	5655		5651		5763	ra
19	5648		5642	R,RA	5658		5656		5947	a
20	5653		5644		5659	RA	5665	CX	5949	BU
21	5724		5649	a	5696	ra	5757	CX	5951	BU
22	5727		5654		5788	a	5758		5954	BU
23	5731		5664		5792		5761	CX	5957	BU
24	5742		5728	a,ra	5796	BU	5762		5964	BU
25	5751	A	5733		5800	BU	5789	a	5968	BU
26	5753	A	5741	RA	5806		5793		5969	BU
27	5765		5766	A,r	5814		5797	BU	5970	BU
28	5785		5787		5821	BU	5803	BU	5972	BU,ra
29	5790		5791		5832	BU	5807	BU	5973	
30	5794	A	5795		5857		5815	BU	5974	
31	5798	A	5799		5861		5823	BU	5975	
32	5804	A	5805	BU	5864		5834	BU,ra	5976	
33	5810	A	5812	BU	5871	BU	5862		5977	

34	5817	A	5820	BU	5878		5873		5981	
35	5827	A	5830	BU	5882		5881		5988	
36	5844		5859		5888		5883		5995	BU
37	5846		5877		5898	BU	5889		5996	BU
38	5855		5887		5902	BU	5894	A	5998	
39	5856		5891	A	5944		5899	BU	6036	
40	5866	CX	5897	BU	5950		5903	BU	6039	A
41	5870		5901	BU	5952		5965		6070	
42	5872	CX	5911	CX	5953		5966		6071	
43	5874		5918		5955		5967		6076	A
44	5875		5927	CX,ra	5958		5971		6090	A
45	5876	BU	5937		5959		5980		6095	OT
46	5879	BU	5940	RA	5961		5983	CX	6096	ra
47	5880		5941		5963		5991		6120	A
48	5884		5942		5982	CX,a	6046		6141	BU
49	5885		5945		6034		6064		6157	BU
50	5886		5946		6074	A	6082	A	6158	BU
51	5890	CX	5948		6081	CX,a	6094	CX	6193	BU
52	5896	BU	5979	a	6086		6101	a	6203	BU
53	5900		5987	a,r,ra	6087	A	6117	BU,a,ra	6206	CX
54	5917		5990	a,r,ra	6088	CX,a	6121		6229	A
55	5919	CX	5993	ra	6089	A	6122	A,ra	6244	A
56	5926	A	5994	A,ra	6091	a,r	6128	ra	6272	a
57	5933		6000	CX,a,ra	6092	RAra	6140		6374	A
58	5935		6001	A	6093	OT	6165	CX	6375	A
59	6243	a	6006	CX,ra	6097	CX,a	6166	Aa,ra	6381	
60	6271		6008	a,r,ra	6102	CX,ra	6168	A	6386	
61	6407		6045	ra	6131		6184	CX,ra	6387	BU
62	9001		6129		6139		6189	a.ra	6655	
63	9002		6136	OT	6154	r	6192	r	6658	
64	9101		6138	BU	6155	BU	6200	r	6740	a
65	9102		6156		6401		6202	ra	9001	
66	9103		6400	a	6445		6210	Aa,r	9002	
67			9001		6653		6212	Aa,r	9501	
68			9201		6656		6402	a,ra	9502	
69			9202		6683		6458		9503	
70			9203		9001		6733		9801	
71					9301		9001			
72					9302		9402			
73							9403			
74							9404			

	Actual	Model
Non-Scheduled Reasons:	A = Aircraft	a = aircraft
	R = Radar	r = radar
	RA = Range Area	ra = range area
	OT = Other	
Canceled Reasons:	BU = Backup or Alternate Mission	
	CX = Canceled for other reasons	

WEEK OF 10-14 FEB 1992

	FEB 10		FEB 11		FEB 12		FEB 13		FEB 14	
01	5480	BU	5482	BU	5485	BU	5487	BU	5238	
02	5494	BU	5496	BU	5497		5498	BU	5488	BU
03	5505		5506		5507	BU	5508		5499	BU,ra
04	5518		5519		5520		5521		5509	
05	5530	BU	5531	BU	5534	BU	5535	BU	5522	BU
06	5542		5543	BU	5544		5545	BU	5536	BU
07	5552		5553		5554		5555		5546	BU
08	5606		5607		5608		5609		5556	BU
09	5816		5772	CX	5822		5825		5610	
10	5867		5818		6150		6003		5826	
11	6002		5869		6161		6152	BU	6153	BU
12	6144	a	6123	RA	6195		6162	BU	6163	BU
13	6159		6134	BU	6228		6231		6251	a
14	6194		6146	BU	6233		6235		6256	
15	6217	BU	6160	BU	6240		6249		6262	
16	6222	BU	6219	BU	6248		6255		6282	
17	6227		6224	BU,a	6250	R	6261		6283	
18	6232		6230	a	6254	a	6270	RA	6325	a
19	6239		6234		6257	RAra	6280	a	6326	
20	6246		6238		6260		6281		6327	
21	6252		6247		6278		6288		6328	BU
22	6258		6253		6279		6292		6329	BU
23	6264	R	6259		6287	BU	6296		6330	BU
24	6265		6266	a,ra	6291	BU	6300	BU	6331	BU
25	6269		6276	RA	6295	BU	6304	BU	6332	BU
26	6274		6277		6299	BU	6308	BU	6333	BU
27	6285		6284		6303		6312	BU	6334	BU
28	6289		6286	BU,a	6307		6316	BU	6340	BU
29	6293	BU	6290		6311	BU	6320	BU	6349	BU
30	6297	BU	6294	BU	6315	BU	6324	BU,ra	6450	BU
31	6301	BU	6298		6319	BU	6338	BU	6495	
32	6305	BU	6302	BU	6323	BU	6345	BU	6505	
33	6309	BU	6306	BU	6337	BU,ra	6408		6509	
34	6313	BU	6310	BU	6344	BU	6471	ra	6516	
35	6317	BU	6314	BU	6380	A,ra	6476	CX	6527	
36	6321	BU,ra	6318		6404		6483	A	6536	
37	6335	BU,ra	6322		6459		6488	A	6540	
38	6376		6336		6460		6502		6542	
39	6377		6383	R	6467		6503		6545	
40	6403	BU	6405	a	6473	r	6507	RA	6549	
41	6410		6422		6492	A	6511		6551	
42	6411		6423		6506		6513	RA	6573	
43	6412		6424		6510		6514		6592	
44	6413		6425		6519		6522		6597	
45	6414		6426		6521		6526		6628	

46	6415		6427		6523	r,ra	6530		6629	
47	6416	RA	6428		6525	RA	6531		6630	
48	6417		6429		6529		6534		6631	
49	6418	RA	6443		6533		6535		6661	
50	6419		6454		6537		6539		6673	RA,a,r
51	6420		6455		6543		6548	a	6678	RA
52	6421		6462	Rr	6546		6550		6680	RAra
53	6436		6466		6547		6554		6681	
54	6437	CX	6468	BU,r	6585		6571		6695	A
55	6438		6470	ra	6590		6586		6699	
56	6439		6477	Rr	6595		6591	a	6701	
57	6442		6481	CX	6612		6596		6702	r
58	6453	a	6489	ra	6613		6617		6710	CX
59	6463	CX	6501	RAra,r	6614	RA	6621		6732	CX
60	6464	a,ra	6512	a,ra	6615		6622		6735	Rr,ra
61	6465		6532	ra	6616	RA	6624		6736	Rr,ra
62	6563		6541	r,ra	6618	RA	6625		6745	a
63	6565		6558	r,ra	6619		6626		6746	
64	6583	a	6564	BU	6620		6627		6747	
65	6588		6567		6633	BU,r	6659		6748	
66	6593		6568		6639	ra	6664		6766	Rr,RA
67	6598		6569	BU	6645	r	6672	Rr,a,ra	6767	R,RA
68	6600		6570		6646	CX,ra	6677		6788	
69	6602		6574	a	6649	r	6679	R	6791	CX,ra
70	6604		6584		6660	CX,r	6697	OT	6793	CX,ra
71	6606	RA	6589		6671	a,r	6698		6804	a
72	6609		6594	a	6684	A	6700	OT,r	6808	RA
73	6778		6599		6687		6712	r	6811	
74	9001		6601		6688	BU,a	6725		6812	CX,r
75	9002		6603		6689		6731	CX	6814	CX,ra
76			6605		6690	BU	6738	r	7007	
77			6607		6691	CX	6741		7123	CX,ra
78			6610		6694		6744	A	7152	RA
79			6611		6696		6749	CX	7263	
80			6711		6709	CX,r,ra	6754	A	9501	
81					6779	OT,r,ra	6755	BU,a		
82					6900	RA,r	6813	r,ra		
83					7155		6961			
84							7052	CX,ra		
85							7333	r		
86							9001			
87							9002			

		Actual	Model
Non-Scheduled Reasons:		A = Aircraft	a = aircraft
		R = Radar	r = radar
		RA = Range Area	ra = range area
		OT = Other	
Canceled Reasons:		BU = Backup or Alternate Mission	
		CX = Canceled for other reasons	

WEEK OF 17-21 FEB 1992

	FEB 18		FEB 19		FEB 20		FEB 21	
01	5614		5836		5837		5768	
02	5835		6132	BU	6005		5838	
03	6004		6197		6394	R	5999	
04	6130	BU	6406		6577		6198	
05	6267	CX	6717	a	6718	a	6728	
06	6343	BU	6719		6720		6729	a
07	6713		6721		6724	a	6730	
08	6714	RA	6722		6726	a	6760	RA,r
09	6715	RA	6723	RA	6759		6764	CX
10	6716		6758		6763	ra	6817	
11	6727		6762	CX	6784		6829	
12	6757	CX	6782		6785		6844	
13	6761		6783		6795	R,ra	6848	
14	6780		6790	R	6796	RAra,r	6858	
15	6781		6815		6816		6862	
16	6792		6822	a	6828		6863	
17	6794	R,ra	6842		6843		6867	
18	6805	Aa	6846	ra	6847		6870	
19	6806	a	6861		6857		6879	
20	6807	CX	6864		6871		6886	R,a
21	6809	BU	6865		6878		6889	r
22	6819		6866		6884	a,r,ra	6894	
23	6841		6869	RAra	6888	ra	6895	
24	6845		6874		6903		6955	a
25	6855	a	6877		6906	BU	6969	
26	6859	R,ra	6896		6909	BU	6978	BU
27	6860	RA	6997		6914	BU	6982	BU
28	6868		6902	BU	6915	a	6987	
29	6875		6905	BU	6919	BU	6992	BU
30	6876		6908	BU	6923		6997	a
31	6880		6912	BU	6926		6999	
32	6881		6918	BU	6929	BU	7005	BU
33	6882		6922		6932	BU	7006	BU
34	6898	CX	6925	a	6935	BU,ra	7014	BU
35	6899		6928	BU	6956		7022	
36	6901		6931	BU	6968		7054	BU
37	6904		6934	BU	6977	BU	7055	BU
38	6907	BU	6950	CX	6981	BU,ra	7056	
39	6910		6954	r,ra	6986	BU	7057	BU
40	6911	BU	6963	Rr,ra	6990	BU	7058	BU
41	6917	BU	6967		6996		7059	CX
42	6921	a	6976	ra	7004	BU	7060	BU
43	6924		6980	BU,ra	7013		7061	BU
44	6927	BU	6985		7021		7062	BU
45	6930	BU	6989		7024		7063	BU,ra

46	6933	BU,ra	6991		7030	BU	7065	BU,ra
47	6936		6994		7042	ra	7067	BU
48	6937		6995	CX	7043	r,ra	7068	BU
49	6938		6998		7046	BU	7072	BU
50	6939	CX,r	7001		7048	BU	7121	
51	6941	CX,r	7002	CX,ra	7050	BU	7122	
52	6942	r	7003	BU	7124		7161	
53	6943	A,ra	7008	BU	7130		7190	
54	6945	BU	7011	BU	7131		7191	r
55	6949	r	7016	BU	7132	BU	7192	RA
56	6962		7018	BU	7134		7197	
57	6966	BU	7020		7137		7199	
58	6974		7023		7140		7200	
59	6979	BU	7027	CX	7261	BU,ar,ra	7201	ra
60	6984	BU	7040	ra	7444	A	7203	BU
61	6993		7041	r	7449	CX,ra	7207	
62	7000	a	7045	CX	7571		7208	
63	7009		7049		7665		7262	RA
64	7019	BU	7051	BU,a	7666		7450	A,ra
65	7265		7053		7667		7605	BU,a
66	7281		7064	CX,r	7669		7614	RA
67	9001	a	7069	CX	7670		7663	a
68	9201		7071		7718		7705	RA
69			7135	CX	7754		7706	
70			7156		9001	a	9001	ra
71			7407		9401		9501	
72			7548				9907	
73			7560					
74			7562					
75			7568					
76			7594					
77			9002					
78			9003					
79			9004					
80			9301					
81			9302					

Appendix H: Comparison of Actual Versus Modeled Results Using Reduced Test Mission Data Sets

The following weekly listings of TW missions are presented by mission number with codes identifying only missions that were non-scheduled. These listings exclude missions that were canceled for any reason.

	Actual	Model
Non-Scheduled Reasons:	A = Aircraft	a = aircraft
	R = Radar	r = radar
	RA = Range Area	ra = range area
	OT = Other	

WEEK OF 03-07 FEB 1992

	FEB 03		FEB 04		FEB 05		FEB 06		FEB 07	
01	5278		5279		5281		5282		5022	
02	5399	ra	5400		5402		5404		5283	
03	5406		5412	RA	5417	ra	5426		5405	
04	5407		5413		5419		5428		5435	
05	5408		5414		5421		5431		5436	
06	5411		5415	RA	5424		5433		5551	
07	5500		5476		5502		5434		5603	
08	5513		5490		5515		5478		5647	
09	5524	A	5514		5539		5503		5652	
10	5537		5538		5601		5516		5657	
11	5547		5548		5645	a	5528		5760	
12	5593		5600		5650		5540		5763	
13	5599		5639		5655	a	5550		5947	
14	5636	a	5640	R	5658		5602		5973	
15	5637		5641	R,RA	5659	RA,ra	5646		5974	
16	5643		5642	R,RA	5696		5651		5975	
17	5648		5644		5788		5656		5976	
18	5653		5649	a	5792		5758		5977	
19	5724		5654		5806		5762		5981	
20	5727		5664		5814		5789		5988	
21	5731		5728		5857		5793		5998	
22	5742		5733		5861		5862		6036	
23	5751	A	5741	RA	5864		5873		6039	A
24	5753	A	5766	A	5878		5881		6070	
25	5765		5787		5882		5883		6071	
26	5785		5791		5888		5889		6076	A
27	5790		5795		5944		5894	A	6090	A
28	5794	A	5799		5950		5965		6095	OT
29	5798	A	5859		5952		5966		6096	
30	5804	A	5877		5953		5967		6120	A
31	5810	A	5887		5955		5971		6229	A
32	5817	A	5891	A	5958		5980		6244	A
33	5827	A	5918		5959		5991	r	6272	a
34	5844		5937		5961		6046		6374	A

35	5846		5940	RA	5963		6064		6375	A
36	5855		5941		6034		6082	A,r	6381	
37	5856		5942		6074	A	6101		6386	
38	5870		5945		6086		6121		6655	
39	5874		5946		6087	A	6122	A,r	665[illegible]	[illegible]
40	5875		5948		6089	Aa,ra	6128	a,r	6740	a
41	5880		5979		6091		6140		9001	
42	5884		5987	r,ra	6092	RA	6166	Aa,ra	9002	
43	5885		5990		6093	OT	6168	A	9501	
44	5886		5993		6131		6189	a,ra	9502	
45	5900		5994	A	6139	r	6192		9503	
46	5917		6001	A	6154		6200	ra	9801	
47	5926	A	6008	r,ra	6401		6202	ra		
48	5933		6045	ra	6445		6210	Aa		
49	5935		6129	a	6653		6212	Aa,r		
50	6243		6136	OT	6656		6402	a		
51	6271		6156		6683		6458			
52	6407		6400	a,ra	9001		6733			
53	9001		9001		9301		9001			
54	9002		9201		9302		9402			
55	9101		9202		9403					
56	9102		9203		9404					
57	9103									

	Actual	Model
Non-Scheduled Reasons:	A = Aircraft	a = aircraft
	R = Radar	r = radar
	RA = Range Area	ra = range area
	OT = Other	

WEEK OF 10-14 FEB 1992

	FEB 10		FEB 11		FEB 12		FEB 13		FEB 14	
01	5505		5506		5497		5508		5238	
02	5518		5519		5520		5521		5509	
03	5542		5553		5544		55[illegible]5		5610	
04	5552		5607		5554		5609		5826	
05	5606		5818		5608		5825		6153	
06	5816		5869		5822		6003		6251	
07	5867		6123	RA	6150		6231		6256	
08	6002		6230		6161		6235		6262	
09	6144	a	6234		6195		6249		6282	
10	6159		6238		6228		6255		6283	
11	6194		6247		6233		6261		6325	
12	6227		6253		6240		6270	RAra	6326	
13	6232		6259		6248		6280		6327	
14	6239		6266		6250	R	6281		6495	
15	6246		6276	RA	6254		6288		6505	
16	6252		6277		6257	RA	6292		6509	
17	6258		6284		6260		6296		6516	
18	6264	R	6290		6278		6408		6527	
19	6265	a	6298		6279		6471		6536	
20	6269		6318		6303		6483	A	6540	
21	6274		6322		6307		6488	A	6542	
22	6285		6336	a	6380	A	6502		6545	
23	6289		6383	R	6404		6503		6549	
24	6376		6405	a	6459		6507	RA	6551	
25	6377		6422		6460		6511		6573	
26	6410		6423		6467		6513	RA	6592	
27	6411		6424		6473		6514		6597	
28	6412		6425		6492	A	6522		6628	
29	6413		6426		6506		6526		6629	
30	6414		6427		6510		6530		6630	
31	6415		6428		6519		6531		6631	
32	6416	RA	6429		6521		6534		6661	a,ra
33	6417		6443		6523		6535		6673	RA
34	6418	RA	6454		6525	RA	6539		6678	RA
35	6419		6455		6529		6548	a	6680	RA
36	6420		6462	Rr	6533		6550		6681	
37	6421		6466		6537		6554		6695	A
38	6436		6470	ra	6543		6571		6699	
39	6438		6477	R	6546		6586		6701	ra
40	6439		6489		6547		6591	a	6702	
41	6442		6501	RAra	6585		6596		6735	R,ra
42	6453	a	6512		6590		6617		6736	R
43	6464	a	6532	ra	6595		6621		6745	
44	6465		6541	r,ra	6612		6622		6746	
45	6563		6558	r,ra	6613		6624		6747	
46	6565		6567		6614	RA	6625		6748	ra
47	6583		6568	ra	6615		6626		6766	R,RA
48	6588		6570		6616	RA	6627		6767	R,RA
49	6593		6574	a	6618	RA	6659		6788	

50	6598		6584		6619		6664		6804	
51	6600		6589		6620		6672	Rr,a	6808	RA
52	6602		6594		6639		6677		6811	
53	6604		6599		6645		6679	R,ra	7007	a
54	6606	RA	6601		6649		6697	OT	7152	RA
55	6609		6603		6671	ra	6698		7263	
56	6778		6605		6684	A	6700	OT	9501	a
57	9001		6607		6687		6712	r		
58	9002		6610		6689		6725			
59			6611		6694		6738	r		
60			6711		6696		6741			
61					6779	OT,r,ra	6744	A		
62					6900	RA	6754	A		
63					7155		6813			
64							6961			
65							7333			
66							9001			
67							9002			

		Actual	Model
Non-Scheduled Reasons:		A = Aircraft	a = aircraft
		R = Radar	r = radar
		RA = Range Area	ra = range area
		OT = Other	

WEEK OF 17-21 FEB 1992

	FEB 18		FEB 19		FEB 20		FEB 21	
01	5614		5836		5837		5768	
02	5835		6197		6005		5838	
03	6004		6406		6394	R	5999	
04	6713	a	6717		6577		6198	
05	6714	RA	6719		6718	a	6728	
06	6715	RA	6721		6720		6729	
07	6716		6722		6724		6730	
08	6727		6723	RA	6726		6760	RA
09	6761		6758		6759		6817	
10	6780		6782		6763		6829	
11	6781		6783		6784		6844	
12	6792		6790	R	6785		6848	
13	6794	R	6815		6795	R	6858	
14	6805	A	6822	a	6796	RA	6862	
15	6806	a	6842		6816		6863	
16	6819		6846		6828		6867	
17	6841		6861		6843		6870	
18	6845		6864		6847		6879	
19	6855		6865		6857		6886	R
20	6859	R	6866		6871		6889	
21	6860	RA	6869	RAra	6878		6894	
22	6868		6874		6884	ra	6895	
23	6875		6877		6888	ra	6955	
24	6876		6896		6903		6969	
25	6880		6997		6915	a	6987	
26	6881		6922		6923		6997	a
27	6882		6925	a	6926		6999	
28	6899		6954		6956		7022	
29	6901		6963	R	6968		7056	
30	6904		6967		6996		7121	
31	6910		6976		7013		7122	
32	6921		6985		7021		7161	
33	6924		6989		7024		7190	
34	6936		6991		7042	r,ra	7191	r
35	6937		6994		7043	r,ra	7192	RA,r
36	6938		6998		7124		7197	
37	6942		7001		7130		7199	
38	6943	A	7020		7131		7200	
39	6949	r	7023		7134		7201	
40	6962	a	7040	r,ra	7137	r,ra	7207	
41	6974		7041	r	7140		7208	r,ra
42	6993		7049		7444	A	7262	RA
43	7000		7053		7571		7450	A,ra
44	7009		7071		7665		7614	RA
45	7265		7156		7666		7663	a
46	7281		7407		7667		7705	RA
47	9001	a	7548		7669		7706	
48	9201		7560		7670		9001	
49			7562		7718		9501	

50	7568	7754	9907
51	7594	9001 a	
52	9002	9401	
53	9003		
54	9004		
55	9301		
56	9302		

Bibliography

1. 3200 SPTW/KRT. *Resource Scheduling and Operational Management System (RESOMS) Overview.* AFMSDP 700-5. Eglin AFB Florida: Headquarters Air Force Munitions Systems Division (AFSC), 15 September 1989.

2. 3246 TESTW. *Mission Scheduling and Control.* AFDTCR 55-2. Eglin AFB Florida: Headquarters Air Force Development Test Center (AFSC), 15 January 1992.

3. 3246 TESTW/DO. *Resource Codes for use with RESOMS.* AFDTCP 55-12. Eglin AFB Florida: 3246 TESTW/DO, 8 April 1992.

4. Antes, Capt Jeffery S. *An Improved Scheduling Algorithm for Eglin AFB Test Ranges.* MS thesis, AFIT/GST/ENS/92M-01. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1992.

5. Baker, K. R. *Resource-Constrained Project Scheduling.* New York: Wiley, 1974.

6. Balas, E. and C. H. Martin. "Pivot and Complement - A Heuristic for 0-1 Programming," *Management Science, 26:* 86-96 (January 1980).

7. Bazarra, Mokhtar S. and John J. Jarvis. *Linear Programming and Network Flows.* New York: John Wiley & Sons, 1977.

8. Brooke, Anthony, David Kendrick and Alexander Meeraus. *GAMS: a User's Guide.* Redwood City California: The Scientific Press, 1988.

9. Chandra, Ashok K. and Larry J. Stockmeyer. "Intrinsically Difficult Problems," *Scientific American. 240:* 140-159 (May 1979).

10. Coffman, E. G., Jr., J. L. Bruno, R. L. Graham, W. H. Kohler, R. Sethi, K. Steiglitz, and J. D. Ullman. *Computer and Job-Shop Scheduling Theory.* New York: John Wiley & Sons, Inc., 1976.

11. Dumond, John. "In a Multi-Resource Environment, How Much is Enough?" *International Journal of Production Research, 30*: 395-410 (February 1992).

12. Fisher, Marshall L. "An Applications Oriented Guide to Lagrangian Relaxation," *Interfaces, 15*: 10-21 (March-April 1985).

13. Foster, Capt Gary G. *Automating the Weekly Flight Scheduling Process at the USAF Test Pilot School.* MS thesis, AFIT/GOR/ENS/92M-10. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1992.

14. Fox, Robert E., President of the Abraham Y. Goldratt Institute. *The Constraint Theory.* Working Paper. 1990.

15. French, Simon. *Sequencing and Scheduling: An Introduction to the Mathematics of the Job Shop.* West Sussex, England: Ellis Harwood Ltd, 1982.

16. Hefferman, Michael P., Chief, Range Scheduling Division. Personal and telephone interviews, 3246 TESTW/DOS, Eglin AFB Florida, 13 July 1992 through 26 February 1992.

17. Jensen, Paul A. *Integer Programming Notes.* Class handout, OPER 620, Integer Programming. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December 1992.

18. Lawler, E. L., J. K. Lenstra, A. H. G. Rinnooy Kan and D. B. Shmoys. "Sequencing and Scheduling: Algorithms and Complexity," *Handbooks in Operations Research and Management Science.* Vol. 4, *Logistics of Production and Inventory.* AB Amsterdam: North-Holland, 1990.

19. Lewis, Harry R. and Christos H. Papadimitriou. "The Efficiency of Algorithms," *Scientific American. 238:* 96-109 (January 1978).

20. Johnson, James H., Senior Range Scheduler - VITRO. Personal and Telephone Interviews, 3246 TESTW/DOS, Eglin AFB Florida, 23 July 1992 through 05 March 1993.

21. Martin, SSgt Scott C., Assistant NCOIC - Resource Management Section. Personal and Telephone Interviews, 3246 TESTW/DOSO, Eglin AFB Florida, 23 July 1992 through 26 February 1993.

22. Moore, James T. Class Notes in OPER 620, Integer Programming. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December 1992.

23. Nemhauser, George L. and Laurence A. Woolsey. *Integer and Combinatorial Optimization.* New York: John Wiley & Sons, 1977.

24. Norbis, Mario I. and J. MacGregor Smith. "Two Level Heuristic for the Resource Constrained Scheduling Problem," *International Journal of Production Research, 24*: 1203-1214 (September-October 1986).

25. Parker, R. Gary and Ronald L. Rardin. "An Overview of Complexity Theory in Discrete Optimization: Part I. Concepts," *IIE Transactions, 14*: 3-10 (March 1982).

26. Rogers, Ralph V. and Preston K. White, Jr. "Algebraic, Mathematical Programming, and Network Models of the Deterministic Job-Shop Scheduling Problem," *IEEE Transactions on Systems, Man and Cybernetics, 21*: 693-697 (May-June 1991).

27. Thesen, Arne. "Heuristic Scheduling of Activities Under Resource and Precedence Restrictions," *Management Science, 23*: 412-422 (December 1976).

28. Winston, Wayne L. *Introduction to Mathematical Programming: Applications and Algorithms*. Boston: PWS-Kent, 1991.

Vita

Major Paul A. McDaniel was born on May 29, 1958 in the District of Columbia. In 1976 he graduated from Suitland High School in Maryland whereupon he attended the U.S. Air Force Academy, graduating with a Bachelor of Science degree in Mechanical Engineering in May 1980. Upon graduation, he entered undergraduate Navigator training at Mather AFB, California whereby he became a distinguished graduate and was assigned as a C-130 navigator at Pope AFB, North Carolina in October 1981. After serving as a Wing Flight Examiner and Special Operations Navigator at Pope he was reassigned to Yokota AB, Japan in May 1986. At Yokota he became the Assistant Chief of the 316th Tactical Airlift Group Standardization and Evaluation Division where he earned some distinction as a member of the 374th Airlift Wing's "Top Aircrew" in 1987. In March 1988, he was reassigned to the 834th Airlift Division at Hickam AFB, Hi where he first worked as a Pacific Airlift Controller overseeing virtually all aspects of strategic and tactical airlift operations in the Pacific. Shortly thereafter, he became the Chief of the Exercise Plans Branch of the 834th where he served as the primary tactical airlift exercise project officer for MAC, USPACOM, and PACAF. During Desert Shield and Desert Storm he was sent to HQ MAC to help in the daily planning and scheduling of strategic airlift forces to and from operating locations in Saudia Arabia and around the world in what resulted as the "largest airlift operation in history". Soon thereafter he entered the School of Engineering, Air Force Institute of Technology, in August 1991.

Permanent Address: 45086 Waiape Place
Kaneohe, Hi 96744

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1993

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
ESTIMATING TEST RANGE CAPACITY

5. FUNDING NUMBERS

6. AUTHOR(S)
Paul A. McDaniel, Maj, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology,
WPAFB, OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GST/ENS/93M-08

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
3246 TESTW/DOS
Eglin AFB, Fla 32542

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Approved for public release; distribution unlimited

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The main focus of this thesis effort was to develop a means to estimate the capacity of the test range complex at Eglin AFB, Florida. For the purposes of this study, test range capacity was defined as the maximum number of missions, of a given set, that could possibly be supported by range resources on any given day. In trying to determine this number, the complexities of the overall multi-resource constrained scheduling problem dictated a more practical approach be taken in modeling the allocation process of range resources to test missions. Therefore, a series of three single-resource, 0-1 integer programming models depicting the allocation of Test Wing aircraft, radars, and range area resources were developed to produce an upper bound estimate of the range capacity for a given set of missions. In actual testing, the Range Area Allocation Model produced some poor results and therefore, cannot be used in its present form. However, both the Aircraft and Radar Models appear to produce legitimate upper bounds on range capacity in all cases. Nevertheless, to insure the goodness of these two models further testing is recommended. In addition, a single model depicting the allocation of these two resources and possibly several others, should be developed in order to better estimate range capacity.

14. SUBJECT TERMS
Linear Programming, 0-1 Integer Programming, Scheduling, Resource-Constrained Scheduling, Test Range Capacity

15. NUMBER OF PAGES
148

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL